·vatories, St. Louis, Mo.

	November.		December.		Five-year averages.	
·.	W. B.	F. P.	W. B.	F. P.	W. B.	F. P.
3	47.8	47.8	50.8	50.8	64.1	63.5
1	35.1	32.9	34.7	33.2	47.5	42.9
2	12.7	14.9	16.1	17.6	16.6	20.6
	2.2		1.5		4.6	

. About 100 yards to the ›servatory is a valley through to the southwest is quite a ck from the observatory to ›r directions are open lawns trees.

is of the Weather Bureau ıst of the observatory build- feet from the nearest trees. ›t above the roof of the ob- ıd. It is on a general level

States Weather Bureau is at Eighth and Olive streets, the river. It is surrounded ›rth smoke from bituminous fuel of the city. The build- et square, and is arranged lower floor.

ted 10 feet above the copper ›bove the level of the street. of the building is a tower the anemometer is exposed structures.

ıns of the daily maximum, re during the year 1891, at › Forest Park stations. It ›n the monthly mean mini- ›ions, and the annual aver- › years 1891–1895, inclusive. able is the difference in the ıres at the two stations, the from 9.0° lower in Septem- 'he extreme differences have ›r.

ıble differences, tables were e minimum temperature re- t 8. a. m. and the previous velocity during the night. the relation between the ıd, and the minimum tem- ›ations. In general it was ased the wind velocity also ›een the minimum tempera- d that both the cloudiness ›ted an influence upon the

ıs it was found that during maximum differences were est months (March and De- ›t, and that they remained ›hs. There were, however, ›s for instance in January, ed 20° on three successive ıs a heavy covering of snow a portion of the time there t it was soon covered with

› minimum temperature dif- › was on the ground at the

park, and it was found that the average difference almost equalled that for September.

The following quotation is from an article "On the influence of the accumulations of snow on climate," by Alexander Woeikoff, Quarterly Journal of the Royal Meteorological Society, Vol. XI, 1885, p. 299.

A covering of snow on the ground acts, firstly, as a bad conductor, rendering the interchange of temperatures between the surface of the ground and the lower stratum of air much slower than when the snow is absent.

* * * * * * *

We see that as a covering of snow protects the upper parts of the ground from radiation and makes the conduction of heat much slower than it would otherwise be, it thus tends to raise the temperature of the soil; but it must have a contrary influence on the lowest stratum of the air, as the snow protects it from the conduction of heat from the ground, an action which, as this is generally warmer in winter, must make the lowest stratum of the air colder. This it undoubtedly does; but in this respect another quality of the snow is even more important, namely, that it is a good radiator of heat.

The influence of smoke from the factories of the city upon the minimum temperature differences has also been studied. It was invariably noticed that on the day preceding a night with an unusually large minimum temperature difference, the wind which had been from the north, became calm. On the eastern horizon the smoke of the city appeared very dense and extended upward to an unusual height, while at the park the sky was very clear. On the following morning the wind changed to the south and gradually increased in velocity.

If two or more consecutive days showed a remarkable difference in the minimum temperatures at our two stations, as was the case in January, 1892, it was because the air remained calm and clear at the park, while the smoke appeared to be heaped up over the city. Invariably at such times the barometer indicated the presence of the crest of an area of high pressure, and its passage accounted for the change in the direction of the wind.

It thus appears that the principal cause of the difference in the minimum temperature readings at the Forest Park and the Weather Bureau observatories is the accumulation of smoke over the city, especially on nights when the sky is clear and the wind light. These conditions favor a rapid radiation of heat from the ground at the park, while the smoke over the city acts like a cloud covering and materially retards radiation.

It is well to notice here the advantages that arise from selecting the northwesterly sections of a city for residence purposes and southeasterly sections for manufacturing purposes.

STUDIES ON THE STATICS AND KINEMATICS OF THE ATMOSPHERE IN THE UNITED STATES.

By Prof. Frank H. Bigelow.

I. A NEW BAROMETRIC SYSTEM FOR THE UNITED STATES, CANADA, AND THE WEST INDIES.

On January 1, 1902, at the 8 a. m. observation, seventy-fifth meridian time, a new system for the reduction of the station barometric pressures to the sea-level plane, was put in operation for the United States, Canada, and the West Indies. The daily weather maps used in forecasting the intensity and the path of storms, and the other allied phenomena, are therefore constructed upon a basis differing from any hitherto used. Students who consult the published weather maps should remember that the series terminating with the above date is not comparable with the others following it, the difference at some stations on the Rocky Mountain Plateau for certain seasons of the year amounting to several tenths of an inch of pressure by the mercurial barometer. The problem of reducing the pressures observed at stations located on the Rocky Mountain Plateau to sea level has always been recognized as one of unusual scientific difficulty, and it has been under discussion in the Washington Office at intervals ever since the establishment of the Government service. So far as can be judged at the present writing the success of the new system is assured, and if this favorable opinion is confirmed by continued use, it will mark the termination of thirty years' effort to solve this question in a practical form. The other plateau districts of the world, Mexico, South America, especially Argentina, south Africa, Australia, and southern Asia, will doubtless profit by the experience of the United States Weather Bureau, on consulting the solution adopted for the United States, Canada, and the West Indies.

Prof. R. F. Stupart, Director of the Canadian Meteorological Office, has courteously cooperated by supplying the necessary data for the Canadian stations, since the common interests of both countries require the adoption of the same methods of barometric reductions. There is no task properly belonging to the Weather Bureau upon which more time and labor has been expended than upon this problem, and the present discussion is the sixth well defined attempt to reach a satisfactory conclusion. The importance of putting the barometric pressures on the elevated plateau, covering one third of the territory for which the official forecasts are made, on a satisfactory scientific basis, fully justifies this work, because it is of primary importance not to attribute to weather conditions any pressure changes that are in reality due to the method of reduction to the plane of reference.

PRELIMINARY REMARKS.

The eastern and central portions of the United States and Canada are generally at levels less than 1,000 feet above the sea, and also the Pacific coast is at low level, so that for these districts the barometric reduction offers no difficulty. Between these, throughout the Rocky Mountain region, there is a rough country where the stations are at different elevations up to 7,000 feet, where the surface temperature conditions range enormously, say from −40° F. to +60° F. on a single map in extreme cases, where the prevailing winds from the Pacific Ocean produce one type of weather on the western slopes of the mountains and another on the eastern, to say nothing of the effect of great arid districts between them, and where the configuration of the mountain valleys, in which many of the stations are located, relative to the neighboring ranges rising up to 12,000 or 14,000 feet in some cases, causes various local peculiarities in the behavior of the barometer.

A description of the construction of our new station pressure normals is properly a preliminary to the solution of the plateau problem. In the years between 1871–1880, while the barometric network was being extended over the plateau districts, many of the elevated stations were at the Army posts where no measurement of the altitude had been made, except by the barometer. We now know that several of these early elevations were seriously in error, say from 10 feet up to 200 feet, and as a change of 10 feet in altitude corresponds approximately to 0.010 inch pressure, the irregularities on the sea-level plane arising from this source alone were not inconsiderable. The gradual extension of the various surveys by the Government over the plateau, together with the railroad levels executed and revised by the different companies, have gradually built up a system of check levels at intersecting points, with accurate differential levels between them, so that now the absolute elevations of the several stations have been determined with much accuracy. An adjustment of these levels was made by Prof. Cleveland Abbe in 1871–72; the work was then taken up by the Geological Survey, and the latest results of these surveys are given in Gannett's Dictionary of Altitudes, edition of 1900. The Weather Bureau was supplied with the corrected altitudes before the publication of this report by the Geological Survey, so that we have had the advantage of this data from an early stage in our own work.

THE ADOPTED STANDARD ELEVATION FOR THE EPOCH, JANUARY 1, 1900.

Besides the incorrect actual elevations which, for one reason or another, have been adopted during thirty years, there have been numerous changes in the elevation of the local offices of the service at the same station, involving many small variations in the altitude above sea level. A very careful reexamination of the station records of the respective stations showed that it was practically impossible to assign correct absolute elevations for the several changes as referred to the sea level, but that it was possible to discover the differences by which the successive changes in height followed each other (that is, the height of the barometer in the new office above or below that in the old office), the series of variations giving a chain of steps up and down in the succession of changes. These were carefully determined, and they were then applied to the elevation occupied by the station at the epoch January 1, 1900, so that the actual heights were thus found for the respective intervals during which the barometer remained in one position, and they were referred in this way to our latest and best elevations as given by recent surveys. Having adopted the elevation for the station at the given epoch, all the recorded actual pressures were reduced to the elevation of 1900 by small differential pressure corrections, so that the entire pressure system becomes homogeneous for the station.

During the years following 1900 a similar plan is to be followed, and all pressures will be reduced back to the standard elevation, so that the series will be maintained strictly comparable throughout the life of the station itself. There is great advantage in this procedure, for two reasons. It was found that in the other attempts to construct pressure normals the earlier computations were readjusted to the latest elevations at the different dates, thus obscuring the record and consuming a great amount of labor without arriving at final results. Also, the reduction tables to sea level, provided for the use of the stations, had to be renewed with every removal, which also consumed much time. On the new plan, however, each year's observations is added directly to a homogeneous station system, and the same reduction table serves without modification in consequence of any local changes. Indeed it is absolutely essential to reach such a basis of operation in meteorology as this, if there is to be made possible a scientific study of the secular variations of the weather, that is, the large problem of why and how the seasons, the climate, and the crops, differ from year to year, this being the next great problem awaiting practical meteorology. Evidently all the cosmical questions involving variations in the radiations of the sun must be compared with as definite a pressure system as this, if scientific results are to be secured from the meteorological data. It may be stated in passing, that in recent years, since the Government has erected large buildings in the cities of the United States, the Weather Bureau offices have been more permanently located, and that the average series of unbroken observations is growing longer than it used to be 10 and 20 years ago. At the same time the elevations are a little higher, because the offices are usually placed in the upper rooms of the lofty federal buildings.

OTHER CORRECTIONS TO THE STATION PRESSURES.

Besides reducing the observed pressures to an adopted station elevation it was necessary to make several more corrections in order to obtain a homogeneous system of normals. (1) The records were thoroughly inspected for the several corrections which ought to be applied to the barometer readings, and we have now a complete list of the barometer numbers and their errors for capilarity, scales, etc. Besides eliminating a few
mistakes, there were two important special correctior
applied. During the interval 1873–1878 a correction c
inch had been added to the Signal Service standard b
ter to reduce it to the supposed Kew standard, but a
of comparisons instituted in 1877–78 showed that th
probably an error, and I have, therefore, removed it fr
new series. A policy prevailed in the office from 1888
to the effect that small errors could properly be neglecte
barometer reductions, and in accordance with it all corr
for scale error and capillarity smaller than ± 0.007 inc
discarded; these have now been all restored. (2) The
tion to standard gravity, at sea level on the forty-fifth p
of latitude, was applied during some years and omitted
others, so that there was irregularity in this respect
gravity correction has now been systematically added
since the beginning of 1873. (3) The hours of simult
observation have been changed several times since the o
of the service, but practically the observations can be g
in two series of selected hours, 7 a. m., 3 p. m., 11 p.
June 30, 1888, and 8 a. m., 8 p. m. since that date. Refe
the mean of 24 hourly observations which is the natura
dard to adopt for the world, these two systems prese
different types of corrections for the North American
nent, and they must be reduced to some one system i
to be comparable. Accordingly auxiliary tables were pr
by which observations at a few selected hours could
duced to the mean of 24 hourly observations, and the di
series have been so corrected since January 1, 1873.
24 hourly corrections will be applied in the future
monthly and annual pressures published by the Weath
reau, so that the fundamental system may remain in
case other hours of observation should ever be adopted,
ing from those now in use.

The application of the corrections for local elevation
error, capillarity, instrumental temperature, gravity, an
nal variation, to the barometric readings, gives a smooth
geneous system of values, from which the mean annual a
mean monthly station normals were derived and check
cross addition; they are noted as B. From these the
and the monthly variations from the general mean we
tained, and they have been thoroughly discussed in th
port of the Chief of Weather Bureau, 1900–1901, Vol. I
order to determine our final station normals, B_n, it was f
necessary to reduce all the short series to a standard fi
the long 27-year series for a large number of stations su
to control the work. There are about two hundred and
five stations, including the Canadians, to be dealt with,
these about seventy-five had a long record of twenty-seven
The run of the monthly residuals increases in irregula
the number of years of observation decreases, but we h
managed the discussion that a short series normal can
duced to the long series normal, and thus the station
upon the standard basis. Whenever a new station is c
by the Weather Bureau a standard normal pressure can r
constructed by a brief computation, and the normal is m
curate than any that could be obtained by fifteen years
observations, since these take up all the turbulent pr
fluctuations due to the general and local circulations, w
is impossible to eliminate, except by the use of the observ
of many years. I may add that my experience with the
metric observations of the United States convinces m
they have always been of a high order of scientific exce
and that the apparent residuals are not in fact due to ac
tal irregularities, but possess general and even cosmica
nificance when they are thoroughly discussed. It has b
mistake to assume that they are not worth the most
treatment in the reductions; on the other hand there is
reason to believe that they will become of prime impo
in the solution of several solar-terrestrial problems.

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THE SEA LEVEL, 3,500-FOOT AND THE 10,000-FOOT PLANES OF REFERENCE.

Having obtained these reliable station pressures throughout the United States and Canada, the plateau problem now comes before us for discussion, in order to reduce the pressures taken at different elevations to the adopted planes of reference, in our case to the sea-level plane, to the 3,500-foot plane and the 10,000-foot plane. All the forecasting problems have been heretofore studied solely on the sea-level plane. But it seems evident that our grasp upon the weather problem will be greatly strengthened if we can study at least three sections through the atmosphere daily instead of the one at the bottom of it. I selected the 3,500-foot plane because this is the average height of the Rocky Mountain stations, to which the least possible reduction is required; also, because it is the average altitude of the base of the cumulus cloud sheet over the eastern districts, upon which observations can be most favorably made with theodolites for gradients of pressure, temperature, and vapor tension. Besides this, it is the altitude at which the moving currents of air are sufficiently distant from the ground to take on their natural configuration when freed from the surface turbulent friction. The 10,000-foot plane was chosen because it is already in use by the Monthly Weather Review to show the monthly mean isobars at a considerable altitude. Furthermore, it is just in the midst of the most rapid-moving horizontal local currents, which build up the cyclones and anticyclones of the middle latitudes and upon which the intensity of storms depends. We know that the isobars on these three planes differ considerably from one another, the closed curves on the lower plane tending to open out into long sweeps on the upper plane, and it is probable that an intercomparison of these varying isobars from map to map will be valuable.

THE NEW REDUCTION PRESSURE TABLES.

It is evidently necessary to possess reduction tables of a perfectly general and flexible kind in order to make the necessary reductions from the several stations to these three planes, and from one plane to the other, in either direction upward or downward. As there are no such tables in print, I have first computed logarithmic reduction tables in English measures, similar to those in metric measures, described in the International Cloud Report of 1898–99, the intervals being for every 100 feet up to 10,000, and for every 10° F. from —40° to + 100°. From these general tables the special station tables were made, giving the corrections to be applied to the station pressure at intervals of 0.20 inch to reduce it to the three planes, respectively. These individual tables contain a correction for the humidity term separated from the dry-air term, a correction for the plateau effect, a residual reduction for a few stations, and two temperature arguments—first, the mean temperature of the air column, and second, the corresponding surface temperature, which is the mean value of two successive 8 o'clock observations, the last always including that hour for which the reduction is made. In order to simplify matters as much as possible for the observers on the stations, the individual station tables are constructed by combining all these corrections and applying them at short intervals of the station pressure, namely, for every tenth of an inch, and for such close intervals of the temperature argument that there shall be no interpolation necessary in this direction in order to obtain the hundredth of an inch of reduced pressure. The result is contained in three tables, one for each plane, with the surface temperature and station pressure as the arguments, and the reduced pressure to the three planes, respectively, in the body of the table, instead of the correction to the observed pressure. There is thus no computation to be done at the station to reduce the observation, and the time consumed in preparing this portion of the cipher code message is very short. The special tables for the stations for use in reduction to the 3,500-foot and the 10,000-foot planes are now being made up, the first and the second forms leading up to them being completed and checked. The tables for reduction to sea level are already in operation, and, so far as known, there is no occasion to modify the reductions at any of the stations. When one considers the large amount of painstaking and careful labor required to produce such a result as this in so complex a problem, it is a pleasure to commend the faithful work of Mr. Heiskell and Miss Hawkins, who have been my assistants in this computation. We hope to be able to make a trial of the working of the pressures on the higher planes before very long.

PREVIOUS DISCUSSIONS OF THE PLATEAU PROBLEM.

After all these preliminary matters have been concluded we may proceed to the really difficult portions of the work. They group themselves around three points, (1) the proper relation between the observed surface temperature, t, and the mean temperature of the air column, θ, corresponding to and substituted for the plateau at the regular intervals for which the general logarithmic reductions were computed; (2) the effect of the plateau itself upon the free air pressure; (3) the residual local effects which can not be classified with the other reductions. These will become clearer to the reader by briefly mentioning the previous methods which have been employed in reducing the plateau pressures to the sea-level plane. (1) From 1871 to June, 1881, the old Guyot tables were used in reducing low-level stations, with the surface temperature and pressure at the time of observation as the argument. Certain annual constants were employed in the cases of high stations. The effect was to cause the isobars to swing widely between the morning and evening hours, and generally the maps were very unsteady. (2) July, 1881, to June, 1886, monthly constants were used for each station, as recommended by the first board on barometer reductions; a single constant answered for each month; these are sometimes known as the Abbe–Upton constants. (3) July, 1886, to June, 1887, the entirely new system of tables by Professor Ferrel was used, thus introducing several valuable principles. Thus, the mean temperature of the preceding twenty-four hours was used instead of that belonging to the respective hours of observation; this was reduced by a vertical temperature gradient, 0.165 per 100 feet, to the approximate mean of the column; the pressure and temperature arguments (B, t) were both employed in entering the table; a special correction for the plateau effect was made in the form C, $\Delta\,\theta$, H, where C=0.00105, $\Delta\,\theta$ is the variation of the temperature from the annual mean, and H is the altitude in units of a thousand feet. The application of the correction for the plateau effect removes the wide range in pressure which occurs on the plateau between summer and winter and reduces it to about the same value on the plateau and in the low level eastern districts. For example, if the mean annual temperature is 50°, that for January 25°, and for July 80°, at a station 5,000 feet above the sea level, we have $0.00105 \times (-25) \times 5 = -0.131$ inch for January, and $0.00105 \times (+30) \times 5 = +0.158$ inch for July. The annual range for high stations on the plateau is about 0.400 inch, and on the low levels it is only 0.150, the difference being simply the plateau effect. Professor Ferrel's tables were not used very long. (4) July, 1887, to December, 1890, a mixture of Ferrel's and Hazen's tables; 1891–1901, Hazen's tables. Professor Hazen constructed a general empirical formula with the object of simplifying the form of the station table. For this purpose he assumed that Mount Washington is the type for the plateau reductions, which is in fact erroneous, since that isolated mountain acts like a free air point, except for the modified value of θ; he assumed that the sea-level pressure should always be exactly 30.00 inches, and at the same time abandoned the pressure argument entirely, with all depending upon it, and computed the correction under these conditions; he rejected the plateau effect correction, and at the same time the change of surface temperature to the mean temperature, θ, was neglected. On applying this system to the daily map it was necessary to make certain arbitrary changes in the computed reductions in order to produce smooth isobars. The great simplicity in the use of this table, having only the surface temperature as argument, seems to have been considered sufficient ground for substituting these tables for Ferrel's, so that from 1891 till 1901, inclusive, they have been employed in making the daily weather maps, although well known to be unscientific and inaccurate. However, it should be said that although the plateau correction was omitted, the practical working of the Hazen method was such as to make the sea-level reductions conform much more closely to the Ferrel system than to the pure Laplacean system, which is correct for free air reductions only. On this account the Ferrel and the Hazen systems work in the same direction for wide departures of the temperature from the annual mean, and to some extent relieve the plateau exaggeration, so that we conclude that the weather maps have served fairly well for the practical purposes of forecasting. (5) 1895–1896, Professor Morrill, in connection with a second board on barometry, rediscussed the problem and computed a set of tables which have not been published, though they have been used for some office work, especially the construction of the sea level and the 10,000-foot plane maps for the MONTHLY WEATHER REVIEW during 1896–1901. The Laplacean free air reduction was computed by special tables for the pressure and the temperature arguments, the value of θ being found by certain adopted average vertical gradients varying for the different seasons of the year; the humidity term was made so as to modify the logarithmic argument; the plateau term was entirely omitted; the tables were in the form of a logarithmic argument, which was not very convenient for rapid work. It was suggested at the same time that a system of constants, daily rather than monthly, be resumed for making the necessary forecasting isobars.

BIGELOW'S SYSTEM OF BAROMETRY, 1902.

We now come to the sixth attack upon the problem, and shall here merely enumerate the steps in the discussion, while the report itself will be found in Volume II, Annual Report, Chief of Weather Bureau, 1900–1901. In substance the principles laid down by Ferrel have been adopted, but the work has been carried far beyond the degree of perfection possible to him nearly twenty years ago, in consequence of the numerous observations at our disposal, whereas Professor Ferrel contented himself with only four years of observation at the plateau stations preceding the time of his studies.

THE SEA-LEVEL TEMPERATURES.

The object to be obtained is to separate the temperature argument from the plateau effect, and to arrive at smooth isobars in correct relations to the winds and the weather throughout the Rocky Mountain region. Having prepared the monthly station pressure normals, as described above, the corresponding station temperature and vapor tension normals were extracted from the office records. The plateau is therefore to be considered as dotted over with 60 or 70 stations where the monthly values of the elements (B, t, e) are known. Assuming an average vertical temperature gradient of 0.30° per 100 feet, the temperatures were first reduced from those given at the station elevation, to corresponding values at selected heights, 500, 1,500, ... 6,500 feet, through short distances; for example, all between 0 and 1,000 feet were corrected to 500 feet, and so on. This concentrates the reductions on a few planes. Then a preliminary set of temperature gra in latitude and longitude was computed from the temper on these few planes, throughout the region west of th sissippi Valley. Certain *centers of reduction* were taken, n where the one hundred and twentieth meridian cross fiftieth, forty-fifth, fortieth, and thirty-fifth parallels o tude, and the one hundred and tenth, one hundredt ninetieth meridians cross the same parallels, and the te tures were reduced by the two horizontal gradients t centers, so that a series of temperatures varying with t tude are now known in vertical directions, at about 1 graphical points. These temperatures were plotted diagram whose abscissas are temperature values and ordinates are altitudes, one chart for each month and the year; average curves were drawn through the plotte peratures and prolonged by best judgment to the sea In the majority of cases it was easy to do this, as the cur was distinctly developed on the diagrams. In this way se temperatures were found at several evenly distributed beneath the plateau, and they were transferred to monthly on the sea-level plane, which were completed for the Paci level districts and for the central and eastern portions United States and Canada. A system of well graded iso was drawn through them for the entire country. Sm justments of the temperatures on the centers of red were required to make the temperatures of the vertical and of the horizontal system interlock harmoniously an together on the sea-level plane. Furthermore, new an accurate temperature gradients in latitude and lon could now be obtained, and the work was therefore re from the beginning to the end with the improved values adopted temperature system is the result of two or thr approximating computations, so that it has at last su reliability to become the substantial basis for further tions. The sea-level temperatures at the several stati easily be scaled from these charts to the tenth of a and such values are called t_0. The use of centers of tion commends itself by the fact that the stations grouped in several ways, since the same station reduced to different centers, and the local inaccuraci thus check themselves out; also by the fact that the amount of computation is much smaller and its accur be controlled by the algebraic differences for uniform The most important result of this discussion is the d ment of well defined temperature inversions during the on the northern Rocky Mountain slope, and in the sun the southern California districts. The former are due dynamic heating of the air blowing eastward over the Mountain divide, and the latter to the excessive surfac ing of the arid region relatively to the temperature of cific Ocean. The introduction of these inversion gr relieves the congestion of the isothermal lines heretofor in these districts.

THE FIRST PRESSURE REDUCTION TO SEA LEVEL.

Finally, the relative humidities were assumed to same for the surface and the sea-level plane through plateau, and from the values of t_0 just found the corres sea-level vapor tensions, e_0, were computed. We ha obtained all the elements required for a reduction of face pressure, B, to the sea-level pressure, B_0, by ta a first approximation $\theta = \frac{t + t_0}{2}$ and the ratio $\frac{e_0}{B_0}$, whe nearly 30.00 inches for all monthly means. Using logarithmic tables, the monthly and annual pressure station in the United States and Canada was reduce level, and the results were transferred to charts. were drawn through these sea-level pressures as accur the data permitted, though the values of B_0 were quite discordant in many places, and the lines somewhat in doubt. Of course the plateau correction was included in the sea-level reduction, as stated above.

TO FIND $t - \theta$.

For practical working by the tables, it was first necessary to determine the relations of t and θ for the entire range of temperatures throughout the year, and this was a task of no little perplexity. It was, however, finally accomplished by two processes. It will be remembered that in the Abbe-Upton system of monthly constants and in the Hazen empirical tables this modification of the surface temperature argument was omitted; that Ferrel used a constant vertical gradient of 0.165° per 100 feet for the year to pass from t to θ, and that Morrill modified this gradient by taking per 100 feet, 0.150° in winter, 0.200° in spring and autumn, and 0.250° in summer. My vertical temperature gradient came out about 0.195° for each month in the year, as the average for the entire plateau, but it was distinctly shown that the several portions of the plateau have very different gradients in the same month, and that for the same locality they change greatly from month to month. Hence it was improper to attempt to deal with the plateau as a whole by using the same temperature gradient; so that, in fact, each station must be considered not only by itself, but also in its relations to the neighboring stations. Finally, special curves have been constructed for temperatures between −40° F. and +100° F., showing the variable difference between t, the surface temperature for twenty-four hours, and the corresponding θ, or the mean air temperature of an air column substituted for the plateau itself. The θ can not be considered as the arithmetical mean temperature between the surface and the sea-level temperatures, because the connecting line is a curve and is not straight, so that it is essential to arrive at an integral mean temperature instead of an arithmetical mean. In a graphical construction the values of θ may be taken as the abscissæ and the differences, $t - \theta$, as the ordinates of a curve, which we seek to construct. The first approximation is evidently equal to $t - \theta = t - \frac{1}{2}(t+t_0) = \frac{1}{2}(t - t_0)$, but the true value may differ from this by several degrees at many of the high stations.

THE FIRST PROCESS.

We proceeded to discuss this point by two distinct methods, the first covering the low temperatures from −40° to +30°, and the second covering the temperatures from about 10° to 90°, so that there shall occur a small overlapping of the two systems in the middle temperatures, and thus allow the two to be joined together. About fifty maps were selected for the winter season, when high pressures and low temperatures prevailed in the Rocky Mountain districts. The pressures for the plateau stations were next reduced to the 3,500-foot plane, because this requires the least average run for the corrections, and hence there is little error arising from selecting the wrong temperature arguments. This configuration of isobars was drawn in red lines; then the low stations near the Pacific Ocean and those in the Mississippi Valley were reduced to sea level; also some of the stations on the mountain slope at moderate elevations were reduced to the 3,500-foot plane as well as to sea level. A set of isobars was drawn on the sea level in blue lines. It was now assumed that the configuration on the 3,500-foot plane is substantially correct for that elevation, and is what the forecaster really wants at sea level for practical work. It was therefore joined with the sea-level system by simply making the red and blue lines flow together and uniting them smoothly; in other words, the upper configuration was depressed to sea level by simply renumbering the isobars in inches as determined by the true sea-level lines, so that a single system of well-balanced isobars covered the country. Next the question was, what is the value of θ that will be required to transform the observed station pressure into the sea-level pressure thus constructed? This was computed from the data in a reverse direction, and the differences, $t - \theta$, found; these were collected by groups for each station on the plateau above 1,000 feet in elevation; the means were taken and plotted as ordinates on the abscissa axis of θ. The result was very instructive, and it at once separated the plateau into groups corresponding to the geographical and climatic location, and showed that all the attempts to use one value of the vertical gradient for a given time is very erroneous. It should be remarked that the value of $t - \theta$ thus found was much too large, because it included within itself the real plateau effect, and this ought first to have been separated; but it gave true relative variations of $t - \theta$ with the range of temperature from −40° to +30°, so that it was only necessary to discover the reduction factor to make the scale of values correct.

THE SECOND PROCESS.

For the warmer temperatures of the year, from +30° to +90°, I took the mean monthly values of t and t_0, surface and sea-level temperature, respectively, and found $t - \theta = \frac{1}{2}(t - t_0)$ and $\theta = \frac{1}{2}(t + t_0)$. These were plotted month by month in coordinate points through which it was easy to draw approximate mean curves. It is noted that during the winter months the ordinates average a little larger for the same values of θ than during the summer months, but as we are limited to constructing a set of tables representing mean conditions, this mean line is the best that can be taken. The variation on the mean line does not often exceed ±1°, and this small change in the resulting argument has really but little influence upon the sea-level reductions which are required. Finally the slope of the second system of curves at the temperatures from +10 to +30° indicated the slope that should be assigned to those found by the first method, that is, they gave us the scale factor for reducing the slope first obtained. The resulting curves are published in the full report, but they can hardly be described without diagrams. Generally speaking, on the north and east of the plateau the $(t - \theta)$ curves have a short ordinate from 10° to 40°, and a considerable increase toward either end; on the central portions of the plateau the curves are nearly flat, the length of the ordinates being about proportional to the altitude; on the western side of the plateau the curves have ordinates which are longest in the central parts and shortest at the ends, that is to say, they are about reversed in shape from those on the eastern plateau. These differing results are largely due to the climatic effects of prevailing winds from the Pacific Ocean, which blow upon the mountain ranges and precipitate their moisture on the western side; the clear skies and cold waves prevail on the eastern side; also there are seen to be certain dynamic heating effects. This subject is, however, too large to expand in this connection.

THE SECOND PRESSURE REDUCTION TO SEA LEVEL.

Equipped with these first approximate values of θ for each month as derived from the surface t, the reductions to sea level were made for the mean monthly normal station pressures, B_0, as already mentioned, and the corresponding isobars were drawn. The sea-level pressures, as shown by the resulting map itself, apart from the reduced values, are really more nearly well balanced and correct than those derived from the individual reductions, because the isobars depend upon the mean result of many neighboring stations, whose mutual claims must be simultaneously satisfied in drawing the pressure lines. The pressures were, therefore, scaled from the maps, giving B_m, and the differences taken between them and the original values as reduced by the computation for $B_0 - B_m$. The outcome was exceedingly valuable and suggestive. For some stations the differences between the map and reduced values were such as to indicate only minor irregularities of a few thousandths of an inch, and these are to be referred to imperfections in the station normals; for others the difference was nearly constant, suggesting an error in the assumed elevation, especially for the old stations at military posts where the elevation had been derived from barometer readings; for others there was a very marked annual period in the differences, which could only be due to an error in the assigned value of the mean temperature, θ, since the differences disappeared at certain points, the signs being reversed between the low and the high temperatures. To be brief, all these sources of difference were removed, the entire work was recomputed a second time, a new system of isobars was drawn, and generally the entire subject was worked over in every available way. The practical effect was a readjustment of some elevations, and of the values of θ, so that the final differences between the map and the reduced sea-level pressures became small, usually less than one hundredth of an inch (0.010 inch), for the long record stations. In a few cases it was found that the constant error, called ΔA, was due to the fact that the initial temperature from which the plateau correction was computed, namely, $C \Delta \theta H$, was not accurately chosen. Usually this was taken as a mean annual temperature, but for some stations, especially on the southwestern edge of the plateau, Santa Fe, Flagstaff, Modena, Independence, etc., it should have been somewhat different. The variation can not be due to elevation, because this has been carefully determined by the surveys, but it must be caused by the local influence of the great desert in connection with the adjacent lofty mountain ranges. There are other stations of low elevation, lying in the eastern or in the Pacific coast districts, where no important error can arise from the reduction data, at which there is a small constant correction required to make the station harmonize with the others, as, for example, Lynchburg, Va., and Portland, Me. These stations have been known, at the Central Office, to act out of perfect harmony with their surroundings, and it is still difficult to understand the causes of these discrepancies. It has been found, furthermore, that the low stations on the north Atlantic and south New England coast and also on the north Pacific coast, are not so perfectly in accord as might be expected, and this may be due to the effect of some land and sea action which is operating in these localities. On the whole the reductions as completed are very reliable when all corrections are applied, that is to about 0.010 inch, under all possible circumstances. We note further that the differences outstanding between the finally adjusted reductions to sea level from the station normal pressures and the map pressures derived from the balanced system of isobars, can be properly considered as corrections to the station normals which will reduce them to the homogeneous or balanced normals. This is distinctly true for stations of short record, e. g., two or three years, where the monthly variations are really considerable, so that by applying these residuals as corrections the station normals are brought to agree with the more correct system which would be derived from a long record of observations. In short, since the long record stations really control the map construction, the short records can be at once improved by applying these small final residuals. Such residual corrections have, therefore, been added to all station normals, and the entire system is thus reduced to a long range homogeneous system and it is called B_n, normal pressure at the station, and B_m, normal pressure at the sea level. These values become our standard normals for further developements and have been so used in the remainder of the work. It is also evident that whenever a new station is opened, we can easily compute a more correct station normal pressure, by starting with the values of B_m as interpolated from the map, than could be found by less than fifteen or twenty years of observations.

PRESSURES COMPUTED ON THE 3,500-FOOT AND THE 10,000-FOOT PLANES.

We have now obtained the following quantities: At th
tions, B_n, t, e, $R. H.$, normal pressure, temperature, vapo
sion, and relative humidity; on the sea-level plane, B_m,
also the ratio $\frac{e}{B}$ was computed for use in the reductions
is next proposed to compute B_1, t_1, e_1, on the 3,500-foot p
and B_2, t_2, e_2, on the 10,000-foot plane. For this purpo
temperature gradients in the free air must first be detern
There are three sources of information available, namel
European balloon ascensions, the American kite ascen
and the Washington gradients derived from computati
the cloud formations observed with the theodolites in 18
These were all thoroughly discussed and they agree tog
sufficiently well to permit the assignment of average gra
from the surface to the two upper planes in the free air.
temperatures were computed on these planes for enoug
tions to permit drawing systems of isotherms with acc
As regards the 3,500-foot plane, the temperatures were
from the free air gradients for stations outside the platea
of lower elevation than 3,500 feet; for points withi
plateau the temperatures on that plane were taken fro
diagrams of vertical temperatures, previously constr
these two systems agree well together, and the isother
continuous. The isotherms on the 10,000-foot plan
simple curves joining the Atlantic and Pacific distric
present no trouble in crossing the plateau. There is o
sult of interest, however, at the surface of the plateau,
I call "gradient refraction." Within the plateau the v
temperature gradient averages about 0.195° per 100 fee
in the free air for the eastern districts about 0.300°
10,000 feet. Now it is evident that this plane is high e
above the plateau to escape the influence of the surfac
ditions, and that it is in the midst of the rapidly driftin
rent of air whose direction is eastward, so that quite u
temperature must prevail along the same parallel of lat
Hence, it follows that by using the smaller gradient 0.1
the surface of the plateau, larger values than 0.300° m
employed from the surface to 10,000 feet, if the averag
dient is to be about 0.300°, such as it would be if the p
were removed. Therefore at the surface of the plateau
is something like an abrupt change in the gradients wl
similar to refraction. Finally, by means of the temper
thus found and the relative humidities, assumed to l
same as for the surface stations, the vapor tension o
3,500-foot plane was computed. For the 10,000-foot pl
was assumed that the relative humidity is 50 per cent
surface amount at all places; this may be subject to crit
but it is near the truth and the effect on the vapor tens
even considerable changes in the relative humidity wo
unimportant at the low temperatures prevailing at th
tude.

THE FIRST COMPUTATION OF B_1 B_2.

Instead of computing the values of t_1, e_1, and t_2, e_2, f
several stations at the outset, the work was much shorte
interpolating the values of all this data on selected po
the charts, namely, centers of reduction; that is, whe
meridians 5° apart, 125°, 120° ...... 65°, cross the pa
5° apart, 55°, 50° ...... 30°. On these centers of red
the sea level B_m, t_o, e_o were also drawn from the cha
that the data is complete for reducing the sea-level pre
to the higher planes. There are two objects gained b
method of discussion; (1) the work of computation is
ened very much; and also (2) the result affords an adr
check on the entire system of reductions, as will be se
what follows. The pressures B_1 and B_2 on the 3,500-foot

and the 10,000-foot plane, respectively, were computed by the logarithmic tables from the data thus obtained on the centers of reduction, and the corresponding systems of isobars were drawn. There now exists the same general harmony in these isobars as on the sea-level plane, and no further corrections are required. It is to be especially noted that in the plateau region the reductions from sea level to the upper planes were made by the same principles as if it had been a free air column, so that all plateau questions are laid aside.

THE SECOND COMPUTATION OF B_1, B_2.

From the B_1 and B_2 charts the pressures belonging to all the stations were interpolated, so that the values of B_1, B_2, to be derived by a direct computation from the station data could be compared as a check. Meanwhile the several station reduction tables to the three planes had been completed, and as a final check the three values, B_o, B_1, B_2, were computed and compared with the values derived from the charts, as explained in the first process. The differences between the two sets of values for B_o, B_1, B_2 were about the same on the three planes; they average about 0.010 inch, the majority being 0.000 or 0.010 inch, a few 0.020 inch, with occasional larger variations due to errors of computation readily detected, or to a local peculiarity, involving a slight readjustment of the corrections in the station tables. These checks, therefore, involved the three distinct parts of the entire discussion, since the process has been arranged practically in a circuit so as to pass from the station B_o to B_1 and B_2 by two separate routes, as described. Hence, (1) the processes of eliminating the plateau effect, and of computing the temperature arguments t and θ were successful; (2) the logarithmic tables and the numerical station tables are in agreement; (3) the charts are accurately drawn, and represent the observations with precision.

As the result of this discussion we have prepared charts for the United States and Canada, giving the monthly and annual normals of pressure, temperature, and vapor tension on the sea-level plane, the 3,500-foot plane, and the 10,000-foot plane, also the relative humidity on the sea-level plane, i. e., 130 charts for these data. There are also charts of gradients of temperature in latitude, in longitude, and in altitude; and charts of pressure variations for a few selected hours referred to the mean of 24 hourly observations. Furthermore, the corresponding numerical values are entered in a summary table for all stations on the sea-level plane, about 265 in number; also for all the stations which were in use by the Weather Bureau, either in the United States, Canada, and the West Indies, at the beginning of the year 1900, or which have been opened for service since that date, making about 175 on the upper planes.

It has not been found necessary to revise any of the reductions to sea level since the tables were put in operation on January 1, 1902, showing that they bear the test of practical work at the hands of many observers. The station tables for the upper planes will soon be tried, and an estimate made as to their value in increasing the accuracy of the forecast system of the Weather Bureau.

We conclude with the remark that the pressure observations and computations of the United States have been at last placed upon a strictly scientific basis, and that all the corrections required by theory will be systematically applied in the future, and the entire series from 1873 onwards will be kept strictly homogeneous. We shall, therefore, for the first time be ready to take up the problems of seasonal variation of the weather, the changes of the climate and crop from year to year, and also the true cosmical problems involved in the radiation effects of the sun upon the earth's atmosphere. Even if we do not ourselves succeed in resolving these questions, we shall have left this portion of the data in form for others to make reliable discussions.

THE TERM INDIAN SUMMER.[1]

By ALBERT MATTHEWS, Boston, Mass., dated December 15, 1901.

However much we Americans may abuse our ever changing climate,[2] there is at least one portion of the year upon which we unite in lavishing praise. It need scarcely be said that I allude to that highly indefinite but always delightful period known as the Indian summer. Connected as this season is, both by name and in popular belief, with the aborigines, it would seem as if the name itself must be of some antiquity; yet, so far as my observation goes, it is not until the year 1794 that the expression Indian summer occurs at all, and not until the nineteenth century that it became well established. If the term is, in fact, barely more than a century old, it would again seem as if we ought to be able to trace out its origin with some certainty. Yet such is far from being the case.

It is proper to define the scope of this paper. In a little more than a century there has grown up, as will soon be abundantly proved, a popular belief that there occurs in our autumn a spell of peculiar weather, and to this has been given the name Indian summer. It has been stated that this spell appears in September; that it comes in October; that it occurs in November or not at all; that it takes place in January; that it lasts for three or five days only; that it extends over a period of more than four weeks; that it is peculiar to New England; that it does not occur in New England at all; that it is now more marked than was formerly the case; that in former years it was more pronounced than it is now; that it has at present ceased to occur anywhere. Amid these various and conflicting assertions, it is not easy to arrive at any definite conclusion; but, eliminating the points in regard to which there is divergence of opinion, it is tolerably clear that this supposed spell of peculiar weather is characterized by three special features—by a warmth greater than that of the few days or weeks immediately preceding, by smokiness, and by haziness. It is true that some scientific writers have denied the existence of the increased warmth and have declared that the alleged smokiness is an optical illusion.[3] But the popular belief—and it is

[1] During the past ninety years much has been written about this term, but until now no attempt has been made to give its history in detail or to collect and examine critically the explanations that have been advanced as to its origin. The term is not found in Webster's Compendious Dictionary (1806), nor in his American Dictionary (1828), nor in his Letter to the Hon. J. Pickering on the Subject of his Vocabulary (1817); nor in J. Pickering's Vocabulary or Collection of Words and Phrases, which are supposed to be peculiar to the United States (1816); but it was recognized in the 1841 edition of Webster. Its history was first indicated in the Oxford Dictionary (1900), and some of the extracts there quoted are also given in this paper. Lest it be thought that I have taken these without acknowledgement, I may be permitted to add that of the nine extracts previous to 1883 quoted by Dr. Murray all but one (from De Quincey, dated 1830) were furnished by me.

My attention has been directed to the term for more than twelve years, and this paper is based on material collected during that period. I am, however, indebted to Prof. Cleveland Abbe for turning over to me the extracts and correspondence in his possession; to the editors of the Dial, the Journal of American Folk-Lore, the Nation, and the New England Historical and Genealogical Register for inserting queries in their journals; and to various correspondents for replying to appeals for information. Wherever this has been obtained and used, due acknowledgment is made in the notes.

[2] In 1789 Dr. Rush said: "Perhaps there is but one steady trait in the character of our climate, and that is, it is uniformly variable." (American Museum, 1790, vii, 334.)

Rush was speaking of Pennsylvania, but his remark is equally applicable to the country at large. The sudden and violent changes which occur in our temperature have for three centuries been a favorite subject of comment.

[3] In 1833 a Baltimorean wrote: "Again this redness of the air together with the mechanical irritation produced by the denseness of the aerial vapor, excites a painful affection of the eyes—this sensation, connected with the smoky appearance of the sky, induces great numbers of the inhabitants of this country to believe that the Indian summer consists of a smoky state of the air produced by burning the vegetable decidua which are collected together in the fall season for this purpose, or as

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STUDIES ON THE STATICS AND KINEMATICS OF THE ATMOSPHERE IN THE UNITED STATES.

By Prof. Frank H. Bigelow.

II. METHOD OF OBSERVING AND DISCUSSING THE MOTIONS OF THE ATMOSPHERE.

INTRODUCTORY REMARKS.

It has been suggested to me that it would be advantageous to many who are interested in the progress of modern meteorology, if the results of the observations on clouds, which were made by the United States Weather Bureau during the years 1896–97, could be put in a more compact form than was ado in the original report.[1]

I am the more inclined to present anew some of my res because of the extensive use that has been made of American observations generally in Dr. J. Hann's Lehrb der Meteorologie, 1901. In this judicious and comprehen summary of the state of meteorology at the end of the n teenth century, Dr. Hann has given very generous recogni to the contributions of the United States, including the Weat Bureau and the Blue Hill Observatory, to the advancemen meteorology. But more important than this, the views the adopted regarding the theories of the circulation of the atn phere in the general and the local cyclones, are fully in acc with the ideas set forth in my report on the cloud observati of 1896–97. It is apparent that meteorology is at last se ing a set of principles founded on observations, which will su sede much that has been heretofore taught in this connect It is therefore important to explain the results of the Weat Bureau observations of 1896–97 as briefly and simply as possi

Taking a very general view of the present state of met ology, it may be proper to classify the conditions as follo The statistical side of the subject is being rapidly worked up that our knowledge of facts is relatively quite complete in matology, and in the diurnal and annual periods of the vari atmospheric elements, namely, pressure, temperature, va tension, and wind direction, in different parts of the wo so far as they prevail in the strata near the ground. Bu the upper strata our knowledge of these elements is still v limited, though it has been considerably extended during past ten years, by the cloud observations, and the balloon kite ascensions. On the theoretical side of static meteorol it may be said that meteorological analysis is well advanc as far as concerns the barometric relations of pressure to height, the temperature and vapor tension variations, and adiabatic thermodynamics generally. The practical extens and application of these formulæ to the upper strata is mak fair progress, and is likely to result in very definite knowle of the true state of the atmosphere throughout its extent. dynamic meteorology, however, that is in the hydrodynan of the atmosphere, affairs are in an unsatisfactory conditi and they can be reclaimed only by pursuing a sound pol regarding them. Looking over the entire field, one is s prised to find that but little has been done in the prelimin and the most necessary stages of this work, in order to m the dynamics of the atmosphere a practical scientific probl It is wasting time to speculate on the mathematical anal of the motions of the atmosphere till we know what the moti are, simply as a case of kinematics. In other words, the pa of motion of the average air currents should be systematic worked up all over the world, as the indispensable preli nary to this study. Of course the obstacle in the way of do this is the invisibility of the air itself, and the labor of mak any observations on its direction and velocity of motion m above the ground. It was for supplying just this need t the international cloud observations of 1896–97 were institut and to it they have contributed a valuable amount of data.

Furthermore, there are the great physical problems c nected with the absorption of the sun's radiant energy in atmosphere, its separation into several kinds of energy—el tric and magnetic energy, heat energy of the visible and inv ble spectrum, and so on. Also there is the question to answered as to the amount of the solar output itself, the va tions from its mean value, how much and what kinds of ene are absorbed in the upper strata, and what in the lower. circulation of the atmosphere in its details really goes back these questions about which we know only a very little. Hen

[1] Report on the International Cloud Observations, May 1 1896, to J 1, 1897, by Prof. Frank H. Bigelow. Report of the Chief of the Weat Bureau, 1898–99, Vol. II.

in a word, the deficiency of modern meteorology is in the dynamics of the upper and middle strata of the atmosphere.

NOTATION AND COORDINATES.

It is not an exceptional fact in the history of science that in the first stages of its development meteorology should have grown up in a rather haphazard fashion, especially as it was dealing with a subject of popular interest, wherein many observers were concerned in getting observations of one kind or another without much regard to their ultimate use in mathematical analysis. As the result of this lack of purpose the confusion became so great between the methods of observing and recording in different parts of the world that when comparative studies were begun the difficulties arising from the want of homogeneity were seriously felt. In order to remedy this state of confusion the International Meteorological Committee have been laboring for years to introduce uniformity into the methods adopted by meteorologists. Much has already been accomplished, and yet there are at least two very important steps that remain to be taken. The first is to use only one system of measures, as the metric in place of the metric and the English; and the second is to conduct and discuss the observations in such a way that in their published form they shall be in perfect order to meet the requirements of the fundamental mathematical equations, either static or dynamic, as they are needed. At present meteorological observations are about evenly divided between the English and the metric systems of measures, since the former is in use in Great Britain, Canada, United States, south Africa, Australia, and India; while the latter prevails in Europe, Asia generally, Japan, north Africa, and South America. Thus it is necessary to translate the figures from one system to the other in preparing the data for the world and for cosmical problems; also two sets of reduction tables are required for all the elements, and two sets of constants in all the formulæ. The more lamentable defect occurs from the fact that the observations are made without relation to their final use in mathematical discussions involving the motions of the atmosphere. Indeed almost nothing has been done to give us the true vector components of motion in the observations, so that they shall be in form for immediate introduction into the equations. The standard equations have been presented by different authors in many equivalent forms, and in consequence the subject has been made unnecessarily complex and difficult for students. The entire body of fundamental equations in meteorology is not very large, but the amount appears to be much greater than it really is by reason of the manifold notations and symbols which have been employed. No more valuable reform could be instituted than that of causing the same physical quantity to be always represented by the same symbol. Thus, for example, barometric pressure B, pressure in units of force P, pressure in units of weight p, would put us in harmony with the leading works in hydrodynamics and thermodynamics; then absolute temperature T, thermometric temperature t, mean temperature of the air column θ, vapor tension e, maximum vapor tension E, absolute weight of vapor μ, weight of the unit volume σ, specific weight ρ, and relative humidity $R.H.$ For rectangular coordinates, displacements (x, y, z) s, velocities (u, v, w) q, accelerations $(\dot{u}, \dot{v}, \dot{w})$ f, angular velocities $(\omega_1, \omega_2, \omega_3)$; for cylindrical coordinates, radius ϖ, angle about axis of rotation φ; for polar coordinates, radius vector r, polar distance θ, angle about axis of rotation λ.

I have felt the weight of these considerations in my comparative studies so much that special pains have been taken in my report to exhibit all the fundamental equations in a standard system of notation, and also to reduce the analyses of several authors to the same standard system for the sake of ready intercomparison. Also, as it seems to be of the utmost importance that the observations taken to determine the motions of the atmosphere should be made in a form appropriate for use in the dynamic equations without further transformation of the data, particular care was taken to make the cloud observations conform to these requirements. It was not possible to bring about this harmony between observations and the analytical theory without introducing some radical changes in the methods heretofore followed by meteorologists, both in the conduct of the observations and in the analytic development of the equations. Accordingly, some account of these changes, as well as of the new results which were deduced from the cloud observations made by the United States Weather Bureau in 1896–97, will be given in the following pages.

THE AXES OF COORDINATES.

The first decision that must be made in establishing a fundamental system of notation has regard to the choice of the axes of coordinates which shall be placed at the base of the entire study, since all the algebraic signs of the quantities depending on the observations which are to be substituted in the equations, must be determined from the adopted positive direction of the axes. This choice depends practically upon two facts, (1) that the radius of the earth is drawn positive outwards, since r increases from the center, and (2) that the right-hand rotation is adopted generally in modern scientific researches. It is true that some of the German mathematicians use the left-hand rotation, but the trend is toward a universal adoption of the right-hand system. If we take as the primary radius that of the earth's axis of rotation in the Northern Hemisphere, as is most appropriate for all scientific problems except in terrestial magnetism, then in polar coordinates the positive angular development in polar distance, θ, is southward; next, with the right-hand rotation about this axis extended upward, the positive development of λ, the angle in longitude, is eastward. Hence, for all systems of coordinates, polar, cylindrical, and rectangular, the azimuth rotation is *from the south through the east, north, and west.* Unfortunately this is in the opposite direction to the azimuth rotation adopted in astronomy, in navigation, and in popular meteorology, because in these branches of science the simple practical consideration has been to follow the sun in its diurnal course, so that azimuth circles and compass cards are numbered around in the clockwise or left-hand rotation. For many statistical purposes, as where average wind directions are to be computed, it makes little difference what system of notation is used, because these data do not look beyond their own immediate purposes. But where we have to deal with a system of equations it is not so. If we take the first set of equations, International Cloud Report (154), for linear velocities due to rotation,

$$u_1 = u - y\,\omega_3 + z\,\omega_2$$
$$v_1 = v - z\,\omega_1 + x\,\omega_3$$
$$w_1 = w - x\,\omega_2 + y\,\omega_1$$

where x, y, z are linear distances, u, v, w are linear velocities, ω_1, ω_2, ω_3 are angular velocities, it is evidently necessary that all these should be defined most carefully. According to the statement given above,

$+\ (x, u)$ are referred to the southward axis,
$+\ (y, v)$ are referred to the eastward axis,
$+\ (z, w)$ are referred to the zenithward axis,

but everything will go wrong if ω_3 is not taken to rotate positively about the axis z, from the south through the east, instead of through the west. Hence, ω_1 turns the axis of y to z, ω_2 the axis of z to x, ω_3 the axis x to y, in cyclical order. Thus it happens that, having adopted this system of rotation, it was found necessary to transform the equations of some well-known mathematical papers in dynamic meteorology to agree with it.

THE AZIMUTH ROTATION.

There is one further difficulty to overcome in regard to the popular meteorological system. An observer determines the direction of the wind by looking toward it and feeling the force of it on his face, or he sets up a wind vane with an arrow pointing in the direction *from which* it blows. This is, however, exactly contrary to the method that mathematical physicists employ, for they describe a stream line by the direction *toward which* it flows. An arrow is drawn on a map "down stream" to show how the current flows, or on the weather map an arrow is said to "fly with the wind." In the latter case meteorologists are inconsistent with themselves, but they adopt the correct principle in their precept on the map. If we describe a wind as having a velocity of so many miles per hour from a given direction, say the north, this must be changed in azimuth through 180° to the south in order to be of use in analytic work. We have thus to make *two reversals* in the common meteorological system: (1) the wind vector must be turned through 180°, and (2) the azimuth must be numbered from the south = 0° toward the east = 90°, north = 180°, and west = 270°. These two changes render it impossible to use the ordinary wind records which are found in meteorological reports without making this transformation. While it is not a very important matter for a few individual cases, it becomes a serious task to do the work of remodeling the figures for a large amount of data. It was for the purpose of saving this labor that the observations of the Weather Bureau were executed in 1896-97 on the correct system, so that all the figures appearing in the final report should be at once ready for use in the equations of hydrodynamics.

In order to facilitate the understanding of the discussion that follows, a chart is introduced to show the scheme of the operations. Fig. 1 gives a comparison of the azimuth system

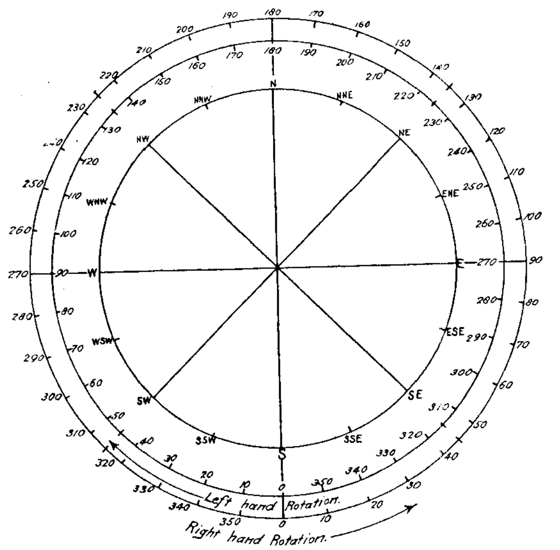

FIG. 1.—Comparison of the two azimuth systems.

Left-hand rotation gives azimuth of "motion from."
Right-hand rotation gives azimuth of "motion toward."
Positive translation is vertically upward.

commonly employed by meteorologists with the one adopted in this report. The former is the left-hand rotation, such as astronomers use, and is counted from the south through the west point of the horizon. In this system, also, the observer faces the wind and gives the azimuth of the direction *from which* it blows. This has been abandoned for the reasons already mentioned, and in place of it is substituted the right-hand rotation, wherein the azimuth is counted from the south through the east point. Here the observer receives the wind on his back and looks toward the direction in which the arrow flies and *toward which* the air is moving. Thus a wind *from the NW* by the former system, with azimuth angle 135°, becomes a wind *toward the SE*, with the azimuth angle 45°, by the latter system. The working out of the results by this system, ready for analytic discussion, as will be seen, involves a minimum of computation, and besides this it reduces all the velocity components to the fundamental rectangular system of coordinates adopted by Ferrel in his treatise, and continued in my "Standard System" which forms a part of the Report.

The Marvin nephoscopes, with which the observations were made, were all graduated to read in a right-hand (anticlockwise) azimuth; the theodolites were also read in the same direction, and the azimuths of Tables 6 and 9 of the International Cloud Report are, therefore, in accord with the coordinate directions of the formulæ which are developed in the following portions of the same Report.

THE COMPOSITION AND RESOLUTION OF THE VECTORS OF MOTION.

It is sometimes necessary to construct the resultant velocity and direction of the motion of the air at a given place out of a large number of individual observations, as in forming charts 20-35, International Cloud Report, for example, and the following practical devices were found convenient. Suppose it

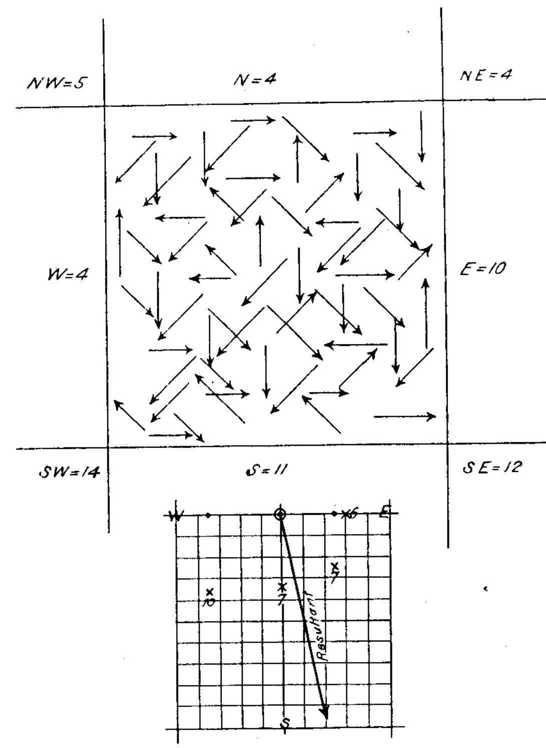

Fig. 2.—Example of the graphic composition of wind vectors.

is desired to determine the velocity and direction of motion in the cumulus cloud level on all sides of a low area, as in the Mississippi Valley. We can best proceed as follows: Take a piece of tracing paper, and select a large number of cloud maps showing about the same configuration of the isobars, so that the centers of the cyclones are located in a given district. Then lay the paper on the cloud maps in succession, and trace the arrows showing the cloud motion wherever an observation is found on the map. Mark the center on the first map and preserve it so as to place it in coincidence with the other cyclonic centers. Continue to fill the paper till some such composite of arrows is obtained as is shown within the square of fig. 2. A scale map of squares, or any other adopted division of areas, is to be prepared as large as the tracing paper, and the two are placed together so that the scale diagram marks off the arrows of the composite map into groups, within each of which it is proposed to find the resultant. Then count out the number of arrows pointing N, NE, E, etc., in succession for eight directions, giving in our example, N=4, NE=4, E=10, etc.; take the excess in four directions, as S = 7, E = 6, SE = 7, SW = 10; plot these results on a diagram and resolve SE = 7 into E = 5 and S = 5; also SW = 10 into W = —7 and S = +7; make the sums E = +4 and S = +19; plot these components and obtain the resultant $V=20$; the angle $\varphi=9°$ can be found by the use of a circular protractor, or it can be computed by the formula $\tan\varphi=\frac{E}{S}$, having regard to a change of algebraic signs for W = —E and N = —S

Wind vector.	Component.	
	E	S
	......	+7
S=7	+6	......
E=6	+5	+5
SE=7	—7	+7
SW=10		
	+4	+19

$$V=20;\ \varphi=9°,\ \text{that is,} = \text{S } 9° \text{ E.}$$

$$\tan\varphi=\frac{E}{S}=\frac{4}{19}=0.21.$$

It is easy to perform a large amount of graphic composition in a short time after a little practise, by arranging this work systematically. In the collection of vectors from the maps the total number will differ from square to square, and it is necessary to reduce the resultant to a common standard number. Suppose we adopt 40 arrows as the standard, then the completed resultant velocity must be reduced in that proportion. Our example contained 64 arrows, hence $20 \times \frac{40}{64} = 12$, and 12 is to be adopted as the average velocity of the motion in the azimuth 9°, that is, S 9° E. These resultants assume that the average of a number of observed directions gives a *relative* velocity of motion, which can be reduced to an absolute velocity as soon as the true mean motion is determined from some other source, as by theodolite observations. Charts constructed in this way are quite correct as to the direction of the motion of the atmosphere, and they give the relative velocities in different parts of a cyclone or anticyclone with sufficient precision to permit further important studies.

By the nephoscope observations the actual velocities in different portions of the area surrounding the center of motion were computed and collected for the several subareas about the highs and lows, as explained in chapter 7 of the International Cloud Report. The relative velocities there recorded can be turned into actual velocities by utilizing the corresponding theodolite observations. The nephoscope refers all the observed motions to the 1000-meter plane, and the theodolite to the actual plane of motion at the height given by the angular measurements. I note that Dr. J. Hann, in his Lehrbuch der Meteorologie, pages 272, 273, and 275, attributes certain cloud heights of the Weather Bureau observations to the nephoscopes, but this is a mistake, because all our heights were determined by the theodolites. The heights associated with the nephoscope observations were adopted for translating the relative velocities of the nephoscopes into actual velocities, and his impression doubtless arose from printing such adopted heights in conjunction with the other data which were derived from nephoscopes.

THE RESOLUTION OF FORCES.

In the study of the motions of the atmosphere at all levels there are two types of resolution of vectors to be provided for in the discussion, the first in rectangular coordinates,

$$+x = \text{South},\ +y = \text{East},\ +z = \text{zenithward},$$
$$-x = \text{North},\ -y = \text{West},\ -z = \text{nadirward},$$

in order to apply them to the motions of the general circulation over the entire hemisphere; and the second in cylindrical coordinates,

$+x$ = radial outward,
$-x$ = radial inward,
$+y$ = tangential counter-clockwise,
$-y$ = tangential clockwise,
$+z$ = vertical upwards on the axis,
$-z$ = vertical downwards on the axis, the results being used in the analysis of cyclones and anticyclones, that is in the local circulations. It is evident that the vectors provided by the theodolite and nephoscope observations, in the form V = velocity and φ = azimuth counted from the south through the east, are ready for simple trigonometric resolution into the velocity coordinates (u_1, v_1) in the four quadrants by using the proper signs. When all the vectors (V, φ) are resolved in the north-south and west-east directions, we can take the mean values by summation and then compute the average motion of the entire mass of air circulating at a given altitude over any locality. It is necessary to obtain these mean directions of motion for the entire circulation, in order to be able to resolve out the special components of local circulation belonging to the cyclones and anticyclones. In the report on the International Cloud Observations the results of this rectangular resolution of the observed mean vectors are set forth in Table 33 as a summary; in Tables 34, 35, and 36 for high areas in the northern and southern portions of the United States; in Tables 38, 39, and 40 for the low areas in the northern and the southern portions of the United States; in Tables 42 and 43 the component southward and eastward velocities in highs and lows, also in selected areas; and in Tables 48, 49, 50, and 51 the seasonal velocities in the upper and lower cloud levels. This data bears directly upon the problem of the upper air currents in the general circulation, and similar data ought to be obtained in all portions of the world.

These rectangular, meridional, and longitudinal velocity components are marked u_1, v_1 in order to distinguish them from the cylindrical components which are designated u_2, v_2. Having constructed the individual components of general motion with the corresponding u_1, v_1 in all the subareas together with the corresponding normal velocities, it is evident that the algebraic differences between them gives the true cyclonic and anticyclonic components, still in rectangular coordinates, as in Tables 44 and 45. The next step is to transform them into cylindrical coordinates u_2, v_2 with the least possible labor. For this purpose it is important to select the subareas surrounding the center of a local circulation in such a manner as will contribute to that purpose. If the areas marked out by the 5° meridians and parallels of latitude are taken, it is impossible to transform the component velocities without a most tedious computation. Such areas are suitable for a simple display of the stream lines, but they do not readily lend themselves to the composition and resolution of vectors of motion.

I have, therefore, adopted the following plan for the subareas surrounding a center of motion. They each have about the same relative area, and they are distributed as far as possible on the cardinal lines of the compass direction. They are numbered with the right-hand rotation, and they are central each on some cardinal point of the compass. Thus on the north-south line 17, 9, 3, 1, 5, 13 are located; on the west-east line 19, 11, 4, 2, 7, 15 are found; while 18, 10, 6, 14 run from NW to SE, and 20, 12, 8, 16 from SW to NE. Hence it is seen that all the N-S and W-E areas are immediately available for composition in rectangular and in cylindrical coordinates, while the rectangular coordinates of the NW-SE and SW-NE areas which come from the first collection need only a simple transformation to become the radial and tangential components of cyclonic circulation. These latter are to be ultimately worked out, and we shall then have three sets of coordinates arranged symmetrically about the center

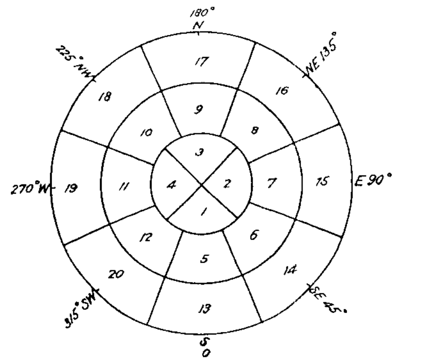

FIG. 3.—Plan of the subareas, azimuths, and compass points, adopted in high and low areas, for the discussion of cloud observations.

The mean of areas 1 to 4 = I, at the average distance 250 km.
The mean of areas 5 to 12 = II, at the average distance 750 km.
The mean of areas 13 to 20 = III, at the average distance 1,250 km.

of the three circles I, II, III at certain evenly distributed distances. The scale of the original diagram, Chart 9, International Cloud Report, is on a radius of 3 centimeters; on the weather maps this is equivalent to 15 centimeters, where 1 cetimeter is equal to 100 kilometers. The adopted scale is therefore *one-fifth* the scale of the daily weather map, and on it 1 centimeter represents 500 kilometers or 310.7 miles, and one millimeter is equivalent to 50 kilometers, or 31.1 miles. All the diagrams of the Report, as far as possible, are reproduced on this scale, but they are readily interpreted on the weather map, so far as linear dimensions are concerned.

VECTORS OF MOTION IN HIGH AND LOW AREAS—RECTANGULAR COORDINATES.

In order to prepare the observations for discussion all those which were made in the same subarea of a cyclone or an anticyclone were collected together in each cloud stratum, and the resultant of all these individual vectors was computed in accordance with the method above described. The individual observations occur in Table 9, and the mode of collecting them is illustrated in Table 29, page 363 of the Report. For convenience, the United States was divided into six districts: 1, Alberta; 2, Lakes; 3, New England; 4, Colorado; 5, West Gulf; 6, South Atlantic; so as to arrive at a conception of the prevailing local characteristics. Hence the heading of the form H—2—15, occurring in several tables, means that in subarea 15, of a high area or anticyclone whose center is in the Lake district, the accompanying observations were made in the several cloud strata, and also at the surface where the instrumental meteorological data are given at the three daily observations. Table 32 contains the resulting vectors V, φ for the northern and southern groups by districts, also for the four seasonal quarters of the year, together with the several mean values, all this extending to the eight cloud strata. In this table the relative velocities are given as derived from the nephoscope, that is on the 1,000-meter plane.

The vectors of Table 32 are plotted on Chart 13 of the Report, the northern in red and the southern in blue, first for the high areas and then for the low areas; also in the seasonal grou that the comparative motions can be studied. It is evident several years work are needed to produce smooth and e balanced mean vectors, which shall truly represent the ave circulation. Especially it will be necessary for the Cana stations to cooperate and supply the vectors wanting i northern subareas of our three northern districts, as this of the circulation usually extends into Canada. Furtherı the vectors of Table 32 are collected together numerica Tables 34 to 40, with a single change, namely, that th locities observed on the 1,000-meter plane have been multi by the adopted mean height of the given cloud stratum. example, the mean height of the cirrus is taken as 9.8 kilom and hence the mean annual velocity $V = 3.6$ of the cirı high area No. 1., page 368, is multiplied by 9.8, and entered at the beginning of Table 34 as $V = 35.3$. I taken the cirrus in each subarea of the high and low are show as an example in Table 1 and fig. 4.

TABLE 1.—*Direction and velocity of motion in high and low areas—rectangular coordinates.**

Compass Point.	Area number.	Cirrus; average height 9.8 kilometers. High. No.	High. φ	High. V	Low. No.	Low. φ	Low. V
S	1	25	86	35.3	7	111	51.0
E	2	16	57	43.1	4	96	40.2
N	3	49	76	31.4	..	...	....
W	4	30	78	36.3	6	104	58.8
S	5	37	66	37.2	50	97	31.4
SE	6	20	67	32.3	33	101	44.1
E	7	23	90	58.8	10	109	36.3
NE	8	43	89	29.4	..	...	....
N	9	51	81	34.3	7	90	49.0
NW	10	34	117	38.2	3	92	27.4
W	11	42	80	37.2	23	77	45.1
SW	12	12	107	14.7	6	105	56.8
S	13	38	95	31.4	27	123	33.3
SE	14	64	82	35.3	70	93	32.3
E	15	28	100	46.1	49	85	34.3
NE	16	58	85	28.4	24	90	30.4
N	17	27	88	36.3	..	...	....
NW	18	25	96	33.3	2	122	39.2
W	19	51	98	29.4	36	71	44.1
SW	20	63	109	30.4	94	90	41.2
No. of obs....		736	...	....	451	...	....
Means		...	...	34.9	...	...	40.8

* Extracts from Tables 34 and 38.

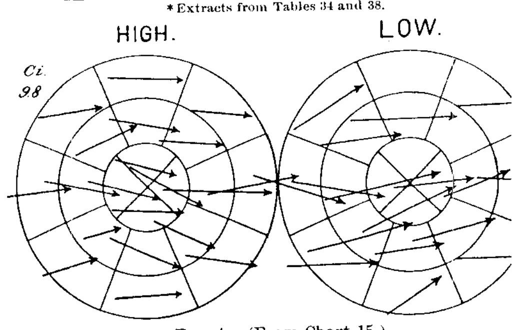

FIG. 4. (From Chart 15.)

These vectors are plotted on Chart 15 (see fig. 4), shows the annual vectors on the several cloud levels in high and low areas. From Chart 15 and the Tables 34–40 are obtained the data for discussing the mean general circulaton over the United States. The mean total velocities in high and low areas, without regard to direction, are found by taking the mean of the velocities in the areas of Tables (34–40) and they are given in Table 33, section 1, as in the following example, Table 2:

TABLE 2.—*Total velocities in highs and lows without regard to directions.**

Clouds.	High areas.				Low areas.		
	Height, kilom.	All groups.	North-ern.	South-ern.	All groups.	North-ern.	South-ern.
Ci	9.8	34.9	38.3	30.4	40.8	44.6	28.3
Ci. S	9.8	39.1	42.6	34.8	39.8	42.5	36.3
Ci. Cu	8.1	33.5	33.9	30.5	39.3	43.8	34.8
A. S	5.9	30.2	31.1	24.1	36.0	39.4	30.5
A. Cu	4.5	23.5	26.6	19.7	29.2	32.6	24.4
S. Cu	2.5	23.3	22.7	18.5	28.6	32.9	21.1
Cu	1.5	11.2	10.9	10.4	14.6	17.4	11.8
S	0.9	11.4	12.2	9.5	11.1	13.2	8.6
Wind	0	4.8	4.9	4.8	5.4	5.3	5.9
Range, per ct.	......	......	......	19	15	......	28
From Table	......	34	35	36	38	39	40

*Extract from Table 33, Section I.

TABLE 3.—*General rectangular components of motion in high and low areas.**

Compass point.	Area number.	Cirrus, average height 9.8 kilometers. High. S+	High. E+	Low. S+	Low. E+
S	1	+ 2.5	+35.2	—18.3	+47.7
E	2	+23.5	+36.2	— 4.2	+40.0
N	3	+ 7.6	+30.5	....	....
W	4	+ 8.6	+35.5	—14.2	+57.0
S	5	+15.1	+34.0	— 3.8	+31.2
SE	6	+12.6	+29.7	— 8.4	+43.3
E	7	0.0	+58.8	—11.8	+34.3
NE	8	+ 0.5	+29.4	....	....
N	9	+ 5.4	+33.9	0.0	+49.0
NW	10	—17.3	+34.0	— 1.0	+27.4
W	11	+ 6.4	+36.6	+10.1	+43.9
SW	12	— 4.3	+14.1	—14.7	+54.9
S	13	— 2.7	+31.3	—18.1	+27.9
SE	14	+ 4.9	+34.9	— 1.6	+32.3
E	15	— 8.0	+45.4	+ 3.0	+34.2
NE	16	+ 2.5	+28.3	0.0	+30.4
N	17	+ 1.3	+36.3	....	....
NW	18	— 5.2	+33.1	—20.8	+33.2
W	19	— 4.1	+29.1	+14.4	+41.7
SW	20	— 9.9	+28.8	0.0	+41.2
Means		+1.97	+33.7	—5.26	+39.4
Normals		**— 1.6**	**+36.6**	**— 1.6**	**+36.6**
Means		+0.66	+40.1	—3.75	+32.7

*Extract from Tables 42 and 43.

Table 2 shows that the velocities are greater in the northern circuit than in the southern, and greater in the low areas than in the high areas. These values must be studied in connection with the barometric gradients to form a theory of the dynamic action in the atmospheric circulation.

The vectors in the form velocity and azimuth, V, φ, are next resolved into rectangular components in the north-south, west-east direction by the trigonometric rules, and the results are given in Tables 42, 43, from which the example in Table 3 is taken.

The means of these components are taken out in two ways: (1) the algebraic mean which gives the rectangular coordinates of motion in the general circulation for the highs and the lows, respectively. The mean of these last forms the normals from which the true cyclonic components are computed, and they are printed in heavy faced type. These results are collected together in Table 33, Sections II and III, from which the following extract is made, Table 4:

TABLE 4.—*Southward and eastward components of velocities in highs and lows.**

Clouds.	High areas. +S —N	High areas. +E —W	Low areas. +S —N	Low areas. +E —W	Means. North.	Means. East.
Ci	+ 1.97	+33.7	— 5.26	+39.4	— 1.6	+36.6
Ci. S	+ 1.65	+32.0	— 9.24	+35.9	— 3.8	+34.0
Ci. Cu	— 0.60	+32.6	— 3.00	+37.2	— 1.8	+34.9
A. S	— 0.37	+27.2	— 4.60	+31.3	— 2.5	+29.2
A. Cu	— 0.07	+22.1	— 2.38	+24.3	— 1.2	+23.2
S. Cu	— 0.32	+16.0	— 4.00	+24.3	— 2.2	+20.2
Cu	— 0.13	+ 5.1	— 0.11	+11.4	— 0.1	+ 8.3
S	— 1.22	+ 5.8	— 1.32	+ 7.8	— 1.3	+ 6.8
Wind	— 0.69	+ 1.1	— 0.40	+ 1.5	— 0.5	+ 1.3
From Table	42	42	43	43	....	....

*Extract from Table 33, Sections II and III.

TABLE 5.—*Component velocities in selected areas between high and low centers.**

Clouds.	Selected areas. Southward. H. 16, 8, 2, 7, 15, 6, 14 L. 18, 10, 4, 11, 19, 12, 20		Northward. L. 16, 8, 2, 7, 15, 6, 14 H. 18, 10, 4, 11, 19, 12, 20	
Ci	+ 0.66	+40.1	— 3.75	+32.7
Ci. S	— 2.11	+36.9	— 3.89	+38.9
Ci. Cu	+ 4.95	+38.7	— 7.34	+32.1
A. S	+ 2.79	+26.5	— 7.47	+31.0
A. Cu	+ 6.24	+23.7	— 7.78	+21.9
S. Cu	+10.22	+22.1	—11.13	+17.1
Cu	+ 6.52	+ 9.6	— 8.13	+ 6.5
S	+ 5.25	+ 7.5	— 7.97	+ 5.1
Wind	+ 2.23	+ 3.2	— 3.25	+ 0.2
Range	....	....	....	....
From Table	42	42	43	43

*Extract from Table 33, Section IV.

The most important remark to be made regarding these extracts is that the observations show an average northern component in the United States in all levels, provided it is a fact that as much air streams through the low areas as through the high areas on the average. (2) The subareas were collected into two groups, those having a southward and those having a northward component. Thus we have a southward component in high areas in 16, 8, 2, 7, 15, 6, 14, and in low areas in 18, 10, 4, 11, 19, 12, 20; but a northward component in high areas in 18, 10, 4, 11, 19, 12, 20, and in low areas in 16, 8, 2, 7, 15, 6, 14. The means from these groups give the mean components of the distinctly southward and northward currents in the different strata. They are collected in Table 33, Section IV, and are reproduced in Table 5:

TABLE 6.—*Anticyclonic and cyclonic components, cirrus 9.8 kilom.**

HIGH AREAS.

Area No.	Rectangular components.				Cylindrical components.	
	u_1	v_1	σ	β	u_2	v_2
1	+ 4.1	— 1.4			+ 4.1	— 1.4
2	+25.1	— 0.4			— 0.4	—25.1
3	+ 9.2	— 6.1			— 9.2	+ 6.1
4	+10.2	— 1.1			+ 1.1	+10.2
5	+16.7	— 2.6			+16.7	— 2.6
6	+14.2	— 6.9	15.7	333	+ 4.9	—14.9
7	+ 1.6	+22.2			+22.2	— 1.6
8	+ 2.1	— 7.2	7.5	286	— 6.6	+ 3.6
9	+ 7.0	— 2.7			— 7.0	+ 2.7
10	—15.7	— 2.6	16.0	190	+13.2	— 9.2
11	+ 8.0	0.0			0.0	+ 8.0
12	— 2.7	—22.5	22.8	263	+14.0	—18.0
13	— 1.1	— 5.3			— 1.1	— 5.3
14	+ 6.5	— 1.7	6.8	345	+ 3.4	— 5.9
15	— 7.4	+ 8.8			+ 8.8	+ 7.4
16	+ 4.1	— 8.3	9.2	296	— 8.7	+ 3.0
17	+ 2.9	— 0.3			— 2.9	+ 0.3
18	— 3.6	— 3.5	5.0	225	+ 5.0	0.0
19	— 2.5	— 7.5			+ 7.5	— 2.5
20	— 8.3	— 7.8	11.4	223	0.0	—11.4

LOW AREAS.

Area No.	Rectangular components.				Cylindrical components.	
	u_1	v_1	σ	β	u_2	v_2
1	—16.7	+11.1			—16.7	+11.1
2	— 2.6	+ 3.4			+ 3.4	+ 2.6
3	......	......			......	......
4	—12.6	+20.4			—20.4	—12.6
5	— 2.6	— 5.4			— 2.2	— 5.4
6	— 6.8	+ 6.7	9.6	136	— 0.1	+ 9.6
7	—10.2	— 2.3			— 2.3	+10.2
8	......	......	....	...	......	......
9	+ 1.6	+12.4			— 1.6	—12.4
10	+ 0.6	— 9.2	9.3	274	+ 6.1	+ 7.0
11	+11.7	+ 7.3			— 7.3	+11.7
12	—13.1	+18.3	22.6	127	—22.5	+ 3.2
13	—16.5	— 8.7			—16.5	— 8.7
14	0.0	— 4.3	4.3	270	— 3.0	— 3.0
15	+ 4.6	— 2.4			— 2.4	— 4.6
16	+ 1.6	— 6.2	6.4	285	— 5.5	+ 3.2
17	......	......	....	...	......	......
18	—19.2	— 3.4	19.6	190	+16.1	—11.3
19	+16.0	+ 5.1			— 5.1	+16.0
20	+ 1.6	+ 4.6	5.0	70	— 2.2	+ 4.6

*Extracts from Tables 44, 46 and 45, 47.

It is important to note that the most rapid currents, both northward and southward in the atmosphere, are in the strato-cumulus level, 2.5 kilometers or 1.6 miles above the ground, and that these currents decrease in velocity above and below that level. The eastward velocity averages about the same in the highs and lows. Hence we infer that the strato-cumulus level is the stratum where the interchanging motion is most rapid between the Tropics and the poles.

VECTORS OF MOTION IN HIGH AND LOW AREAS—CYLINDRICAL COORDINATES.

We can now compute the true cyclonic and anticyclonic rectangular components by simply subtracting the normal values (heavy type, Table 3) from the individual subarea values in each cloud stratum. In this way the components u_1, v_1 of Tables 44, 45 are found, and an example is given above, in Table 6, in the cirrus level for the high and low areas. Against subareas 6, 8, 10, 12, 14, 16, 18, 20 there are placed the corresponding vectors (σ, β), velocity and azimuth, because these are needed in resolving the rectangular into cylindrical components. In the other subareas the components are already in the N–S and W–E directions and they can be transformed by mere inspection into the corresponding cylindrical coordinates, which are radial and tangential to a circle about the central axis, and they give u_2, v_2, as in Table 6, and fig. 5 following, in which $+ u_1 =$ southward, $+ v_1 =$ eastward, $+ u_2 =$ radial outward, $+ v_2 =$ tangential anticlockwise.

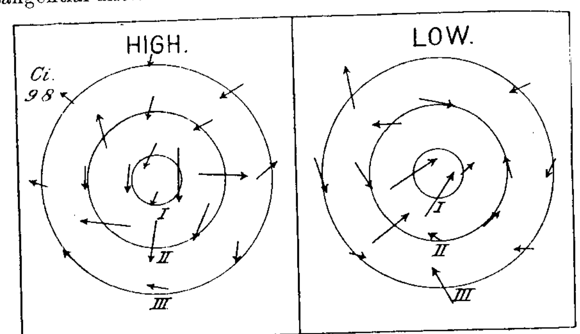

FIG. 5. (From Chart 16.)

Those which do not lie on the north-south west-east lines are transformed as follows: The coordinates u_1, v_1 are compounded into the vector (σ, β), σ being the linear distance from the center, and β the angle from the south. Thus in cirrus 6, high, Table 44, $u_1 = 14.2$, $v_1 = -6.9$, and we find $\sigma = 15.7$, $\beta = 333°$, which can be verified by reference to Chart 16 *a*. In the same way all the vectors under subareas 6, 8, 10, 42, 14, 16, 13, 20 which lie on the SE–NW and NE–SW diagonals have been reduced to vectors (σ, β).

To reduce these to the cylindrical coordinates, we subtract 45° from β in 6 and 14, 135° from β in 8 and 16, 225° from β in 10 and 18, 315° from β in 12 and 20. Then the vector $[\sigma\ (\beta - \alpha)]$ is resolved at once into u_2, v_2. Thus 15.7, 333° of Ci. 6, high, Table 44, becomes 15.7, 288°; thence $u_2 = 4.9$ $v_2 = -14.9$, as in cirrus 6, high, Table 46, and as can also be verified on the Chart 16 *a*. In this way the coordinates of the anticyclonic and cyclonic components, Tables 46, 47, have been found. We have thus the data in such form that one more concentration can be made. If we assume that a symmetrical gyratory circulation is represented by the coordinates of Chart 16, it is now necessary simply to take the mean values of the cylindrical coordinates lying on each circle; that is to say, the mean of the areas 1–4, 5–12, 13–20, respectively. This has been done, and they are entered as I, II, III, in the next section of the same Tables 46, 47. The means of I, II, III, themselves, are also entered on the next line, as average values for the entire circulation in each cloud level. These can be most conveniently studied by reference to Charts 17, 18, where specimen vectors are plotted for the several levels.

The rectangular components were transferred to Chart 16 and drawn so that the vectors shall be central on the circles I, II, III, which run through the middle of the respective adopted subareas. In order to get some idea of the average cyclonic and anticyclonic vectors in the different levels, the mean values of the vectors found on the circles I, II, III, respectively, were taken, and these give the relations between the inner and the outer portions of the masses of air in motion in cyclones and anticyclones. They are shown in Charts 17 and 18. To secure one more concentration of the data, and to further eliminate the local defects, the nine levels were reduced to three by taking the means of the three upper, the three middle, and the three lower strata together, respectively, and these are shown on Chart 19. The following small Table 7 gives the corresponding numerical results; it is Table 52 of the cloud report.

TABLE 7.—*Mean components grouped in three levels.**

MEAN ANTICYCLONIC COMPONENTS.

		I.	II.	III.
Upper level.	u_2	— 3.3	+ 3.9	+ 2.2
Ci., Ci. S., Ci. Cu.	v_2	— 4.5	— 5.2	— 4.8
	σ	5.6	6.5	5.3
	β	234	307	294
Middle level.	u_2	0.0	+ 4.2	— 0.8
A. S., A. Cu., S. Cu.	v_2	— 7.1	— 6.6	— 9.3
	σ	7.1	7.9	9.3
	β	270	303	265
Lower level.	u_2	+ 3.3	+ 3.0	+ 1.8
Cu., S., Wind.	v_2	— 4.1	— 7.0	— 6.2
	σ	5.3	7.6	6.4
	β	308	294	287

MEAN CYCLONIC COMPONENTS.

		I.	II.	III.
Upper level.	u_2	— 1.2	— 6.8	— 1.8
Ci., Ci. S., Ci. Cu.	v_2	+10.2	+12.3	+ 0.7
	σ	10.3	14.0	2.0
	β	96	119	161
Middle level.	u_2	— 7.3	+ 0.3	+ 1.6
A. S., A. Cu., S. Cu.	v_2	+18.6	+14.4	+ 5.2
	σ	20.0	14.4	5.5
	β	111	89	73
Lower level.	u_2	+ 0.3	— 2.4	— 1.5
Cu., S., Wind.	v_2	+ 7.9	+ 6.3	+ 3.8
	σ	8.0	6.7	4.2
	β	88	111	112

* Copy of Table 52.

It is evident that it would be of great advantage to meteorology to have similar observations continued systematically in the United States, so as eventually to obtain perfectly reliable vectors of motion throughout the atmosphere, and they should be extended to all parts of the world as rapidly as practicable. It is not very safe to draw conclusions extending to the entire atmosphere from the observations made at a few selected localities, such as those in the United States or Europe, but it seems to be necessary for us to do so in the present incomplete state of meteorology. Moreover, we must use the material we now have in discussing what are the fundamental principles of dynamics that can be admitted into the theory, and accordingly I shall proceed to take up the observed general circulation and the local circulations, and compare them with the existing theories in order to arrive at such views as will probably determine the theoretics of the dynamic meteorology of the future.

NOTES AND EXTRACTS.

MR. C. F. R. WAPPENHANS.

Mr. Carl F. R. Wappenhans, for many years a member of the Signal Corps and of the Weather Bureau, died at Arco, Switzerland, February 4, 1902. Mr. Wappenhans was born at Berlin, Prussia, in 1834, served as an officer in the United States Navy from 1862 to 1868, joined the Signal Corps on January 9, 1871, was placed on the retired list as first class sergeant on December 28, 1891, was appointed local forecast official in the Weather Bureau on the same date, and resigned on August 31, 1901. He was in charge of the station at Indianapolis, Ind., from January 30, 1871, until the date of his resignation, with the exception of four years, from 1879 to 1882, when he was in charge of Detroit, Mich. Mr. Wappenhans was a man of most kindly and genial disposition, and a faithful and efficient official.—*H. E. W.*

THE WEATHER OF THE MONTH.

By Prof. ALFRED J. HENRY, in charge of Division of Records and Meteorological Data.

CHARACTERISTICS OF THE WEATHER FOR FEBRUARY.

The weather of February, 1902, was much like that of February, 1901. In the interior low temperatures and great dryness prevailed while on both coasts the precipitation was above the seasonal average. A remarkable feature of the month was the persistence of a ridge-shaped area of high pressure that extended from Tennessee northwestward evidently beyond the field of observation. This ridge of high pressure seems to have been formed and maintained by the movement southeastward along the eastern slope of the Rocky Mountains in British Columbia of areas of high pressure of rather small extent, yet sufficient to prevent areas of low pressure from crossing the Rocky Mountains in the neighborhood of the forty-eighth parallel of latitude. All of the storms of the month therefore except the last one moved southeasterly over the Plateau region to the Texas coast, thence easterly along the Gulf coast, and northeastward along the Atlantic coast to New England. As in 1901 a great depression persisted over the North Atlantic off the Canadian Maritime Provinces. Pressure was also remarkably low off the north Pacific coast and the rainfall in that region was extraordinarily heavy. The temperature was

réales et des variations et perturbations du magnétisme terrestre. Pp. 591–594.
Deslandres, H. et Décombe, —. Sur la recherche d'un rayonnement Hertzien émané du soleil. Pp. 527–530.
André, G. Action de la température sur l'absorption minérale chez les plantes étoilées. Pp. 668–671.
Le Cadet, G. Dispositif d'électroscope atmosphérique enregistreur. Pp. 745–747.

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Marty, G. Régulateurs de température et d'humidité. Pp. 196–198.
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Rabot, Charles. Les pluies de poussière et les glaciers. Pp. 259–260.

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Lemoine, Georges. Étude sur l'hydrologie du Bassin de la Dordogne. Pp. 25–42.
Moureaux, Th. De l'influence des courants "vagabonds" sur le champ magnétique terrestre à l'observatoire du Parc Saint-Maur. Pp. 42–46.

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Vanderlinden, E. Observations sur la hauteur de neige lors du dernier dégel. Pp. 26–27.
Very, F. W. Un cycle cosmique. Pp. 59–68.
Arctowski, Henryk. Note sur les phénomènes crépusculaires observés à bord de la "Belgica." Pp. 68–79.

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La Vaulx, Henry de. Le voyage du "Mediterrenéen." Pp. 53–58.
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Gautier, R. Résumé météorologique de l'année 1900 pour Genève et le Grand Saint-Bernard. Pp. 148–181.

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Bouty, E. Einige Bemerkungen zur Absorption der Erdstrahlung durch die atmospherische Kohlensaure. [Note on article by Knut Angström.] P. 167.
Sagnac, G. Recherches sur le bleu du ciel. [Note on memoir by Giusseppe Zettwuch.] Pp. 239–240.
Baillaud, Jules. Atmospheric radiation. [Note on memoir by Frank W. Very.] Pp. 240–243.

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Grohmann, —. Die klimatischen Verhältnisse des Königreiches Sachsen in ihrer Abhängigkeit von Luftdruck und Windursprung. Pp. 32–40.
Assmann, Julius, Sr. Die atmosphärischen Begleiterscheinungen des Gewitters vom 2 Januar 1902. Pp. 41–42.
Brennecke, W. Sylvester auf dem Brocken. Pp. 43–45.
Sieberg, A. Ein Beispiel für die Wirbelbewegungen in Cumulus-Wolken. Pp. 49–53.
Grohmann, —. Die klimatischen Verhältnisse des Königreiches Sachsen in ihrer Abhängigkeit von Luftdruck und Windursprung. Pp. 53–64.
—— Winterliches Gewitter. Pp. 67–68.
Brennecke, W. Bestimmung der Schneehöhe auf dem Brocken. P. 69.

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—— Klimatologische Mittelwerte für ganze Breitenkreise. Pp. 219–224.
—— Die Abnahme der Temperatur innerhalb der Gebiete hohen und niedrigen Luftdrucks. P. 314.

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Bjerknes, V. Cirkulation relativ zu der Erde. Pp. 97–108.
Draenert, F. M. Das Klima von Juiz de Fora im Staate Minas-Geraes. Pp. 108–119.
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—— Sir Henry Gilbert. P. 119.
—— Der erste vollständige Jahrgang meteorologischer Beobachtungen auf der Zugspitze. P. 119–120.
Hann, J. Klima von Konstantinopel. Pp. 120–123.
Hann, J. Zur Meteorologie von Peru. Pp. 123–128.
Leonhard, —. Klima der Insel Kythera. Pp. 128–131.
Hann, J. Klima von Asuncion, Paraguay. Pp. 131–133.
Lenard, P. Ueber die Elektricitätszerstreunung in ultraviolett durchstrahlter Luft. Pp. 133–135.
Erk, F. Die telegraphische Verbreitung der Wettervorhersage in Bayern. Pp. 135–136.
Hann, J. Der jährliche Gang der Temperatur-Unterschiede zwischen den beiden meteorologischen Stationen in Catania (Universität und Astrophysikalisches Institut.) P. 136.
Trabert, W. Die Korrektion der Registrirapparate wegen Trägheit. Pp. 136–139.

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Pittier, Enrique. Experimentos de aclimatacion en los repastos del volcan de Turrialba. Pp. 1–6.

STUDIES ON THE STATICS AND KINEMATICS OF THE ATMOSPHERE IN THE UNITED STATES.

By Prof. FRANK H. BIGELOW.

III.—THE OBSERVED CIRCULATION OF THE ATMOSPHERE IN THE HIGH AND LOW AREAS.

GENERAL DESCRIPTION OF THE VECTORS OBTAINED BY OBSERVATION.

In my original report on the cloud observations of 1896–97, it was necessary to present the data in such a form that other students could have the facts at first hand. As then pointed out there are several subareas in which only a few observations were located, and they are quite unevenly distributed about the central axis, so that the final vectors as computed do not have the well-balanced smoothness which it is desirable to obtain. The data was given in the form of tabulations and also of diagrams, since it is easier to secure from the latter a clear mental picture of the average configuration of the vectors of motion in all parts of the cyclones and anticyclones. Having done this at the outset I now proceed to draw up an average system of vectors by the process of graphic adjustment. There will still remain some uncertainty as to the finer details in certain areas where the motion is more complicated, but I am quite sure that the results presented in this paper give a very correct idea of the mean motions of the atmosphere over the United States and Canada. It would require a good deal more labor in observation and computation than was involved in a single year's campaign to bring the work to that degree of perfection which is desired by meteorologists; this work must undoubtedly be expended in the interest of science some time in the future. Especially for the higher strata of the high and low areas do we need more observations, because the powerful eastward drift quickly obscures the comparatively small gyratory components that penetrate up to the high levels. It should be remembered that the vectors in hand were procured by observing the motions of the air almost daily throughout the year, and consequently that all kinds of weather have entered our final results. If we want the characteristic circulation pertaining to well developed cyclonic and anticyclonic

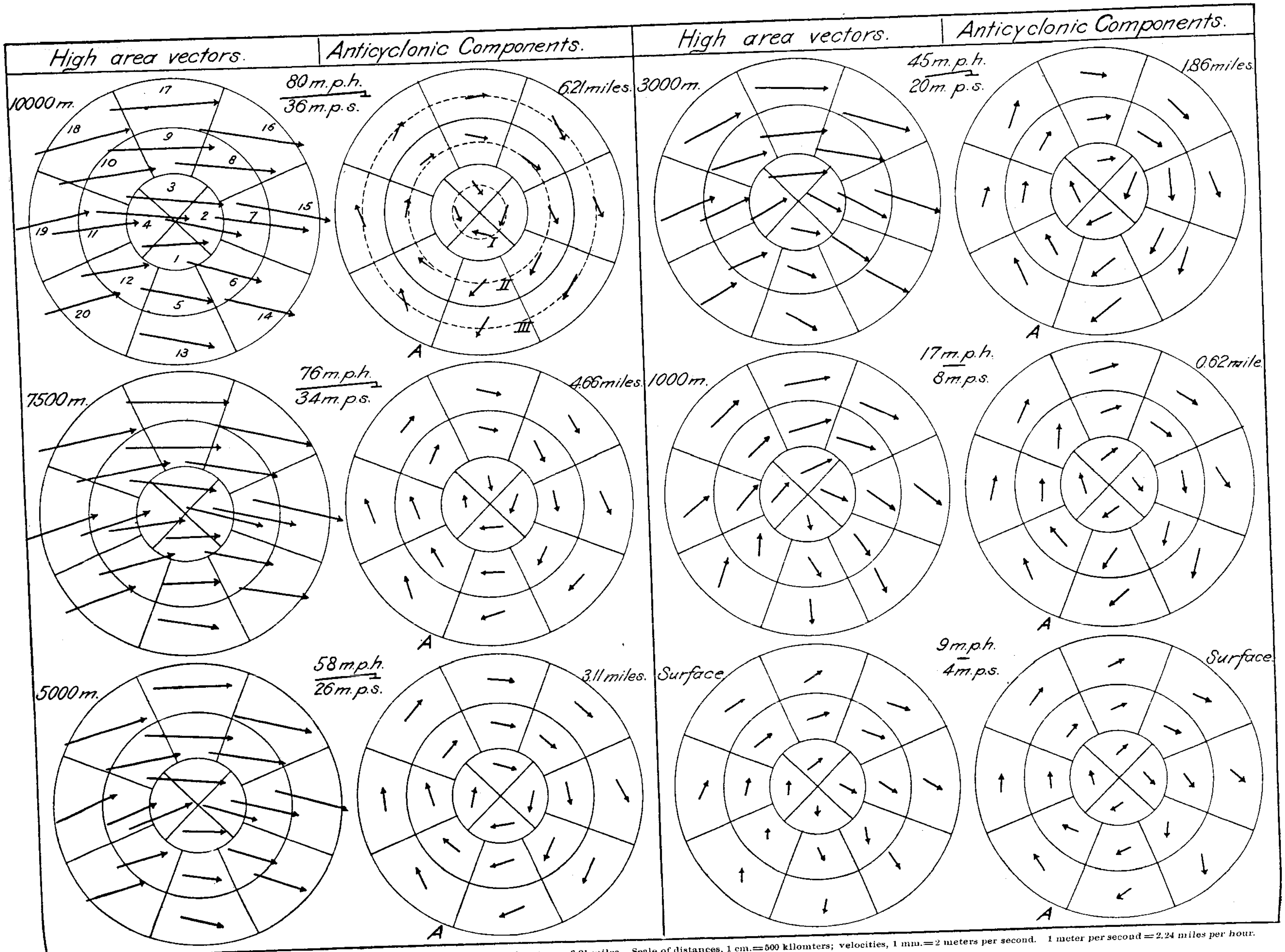


FIG. 6.—Adjusted mean vectors of direction and velocity of motion in high areas. 10,000 meters = 6.21 miles. Scale of distances, 1 cm. = 500 kilometers; velocities, 1 mm. = 2 meters per second. 1 meter per second = 2.24 miles per hour.

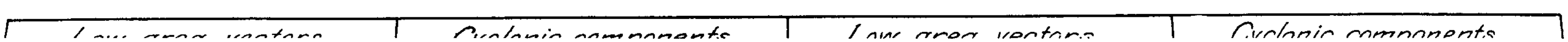


FIG. 6.—Adjusted mean vectors of direction and velocity of motion in high areas. 10,000 meters = 6.21 miles. Scale of distances, 1 cm. = 500 kilometers; velocities, 1 mm. = 2 meters per second. 1 meter per second = 2.24 miles per hour.

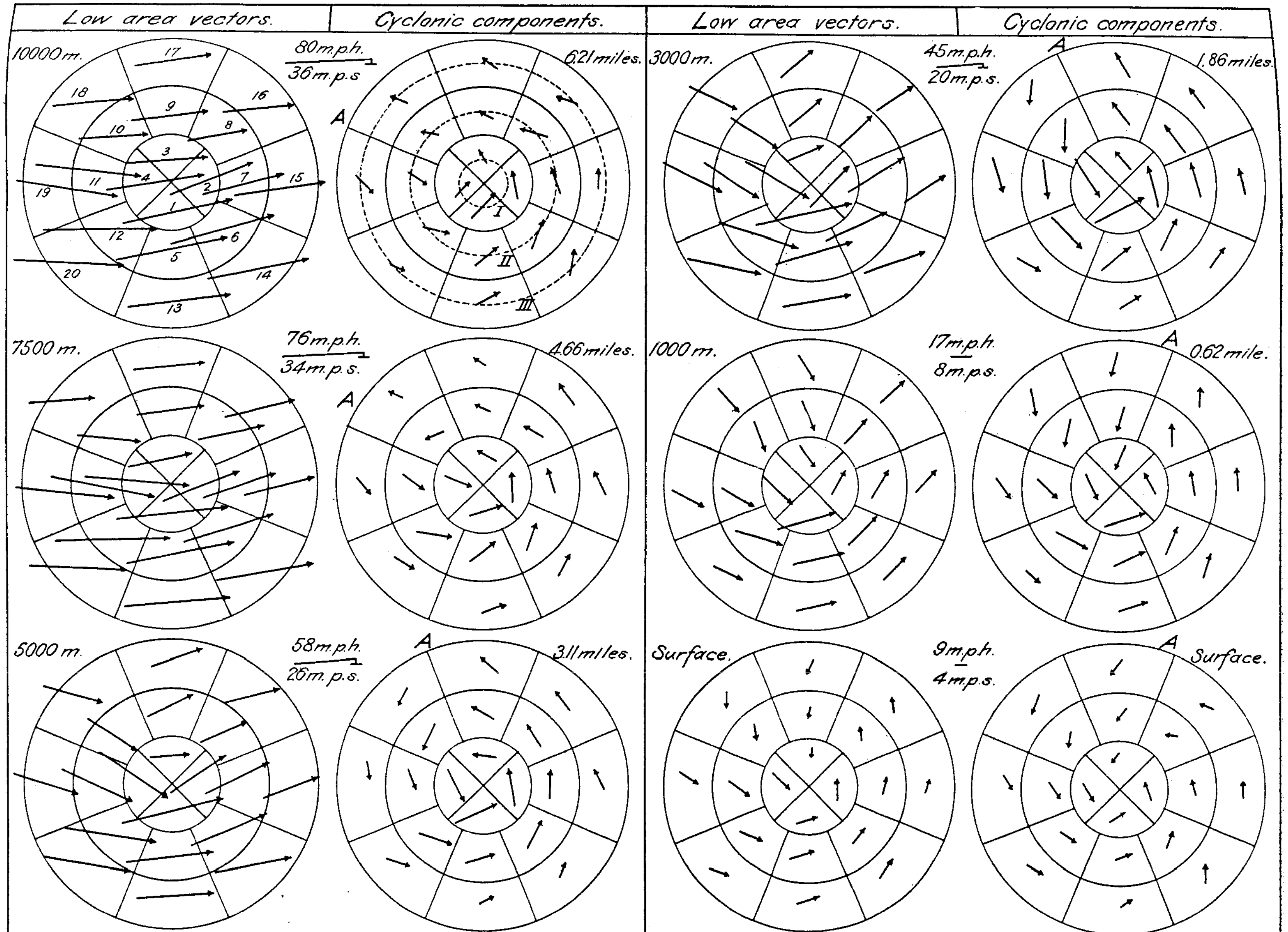


FIG. 7.—Adjusted mean vectors of direction and velocity of motion in low areas. 10,000 meters = 6.21 miles. Scale of distances, 1 cm. = 500 kilometers; velocities, 1 mm. = 2 meters per second. 1 meter per second = 2.24 miles per hour.

configurations, it can be found only by selecting the vectors on certain days when these types are strongly organized, and discussing them by themselves. Under the circumstances that pertained to the cloud year we were obliged to put every kind of observation together, without selection, and this necessarily produced many irregularities in the final scheme of vectors. I have now gone over the data again, and by studying the balance of the various parts of the system have brought out the revised scheme herewith presented. Its well-balanced symmetry speaks strongly for its average accuracy, and it will be possible to draw out of it many important conclusions of fundamental value for theoretical meteorology. We may remark that none of the principles enunciated in the original report have undergone modification by this present review.

By comparing the vectors of figs. 6 and 7 of this paper with Tables 34-47 and Charts 15 and 16 of the Cloud Report, one may readily examine all the changes that have been adopted, and may also discover how closely these charts represent the mean system indicated by the original observations. Instead of carrying the discussion through on the mean cloud levels where the observations were made, it is more convenient to select certain planes upon which the average vectors are established for further discussion.

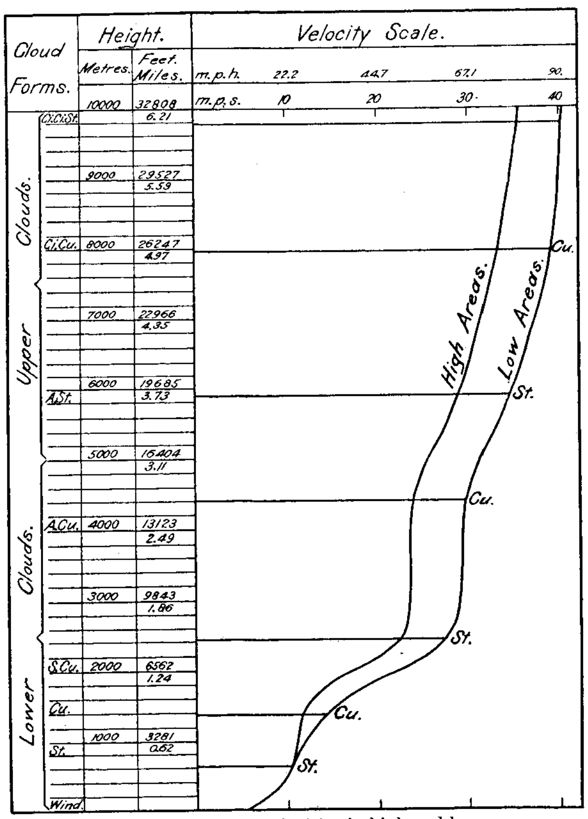


FIG. 8.—Total eastward velocities in high and low areas.

It is necessary first to establish the normal mean annual vectors representing the eastward drift to which the observed vectors are to be referred, in order to decompose them and obtain the anticyclonic and the cyclonic vectors by themselves. These normal vectors are given in Table 4, which is an extract from Table 33, III, International Cloud Report. The eastward velocities are also represented by fig. 8, total eastward velocities in high and low areas, which shows that the low areas drift eastward more rapidly than the high areas at all levels above the stratus, where they have about the same velocity, and that they drift northward in the United States, in the upper levels, at a somewhat higher velocity than in the low levels. It is important to bear in mind that the results of our observations pertain only to the central portions of the North American Continent, eastward of the Rocky Mountains, where the cyclonic storm tracks have on the average a northeastward direction toward the Gulf of St. Lawrence. On the Rocky Mountain slope they have a movement toward the south before recurving in the Mississippi Valley. Generally the eastward drift has a small northward or southward component varying in the different parts of the world, and it is not quite proper to draw general conclusions for the entire hemisphere from the motion of the atmosphere in one district. Furthermore, since the cyclonic areas have a special vertical progression of their own, it seems probable that the average velocities observed in the high areas represent the true motion of the total mass of circulating air more correctly than would the mean of the high and the low areas. The normal eastward and northward components have, therefore, been chosen a little in excess of those given by observation for the high areas, and they are given in Table 8.

TABLE 8.—*Normal component velocities on six selected planes.*

Height.	Eastward velocity.	Northward velocity.	Height.	Eastward velocity.	Northward velocity.
Meters.	*m. p. s.*	*m. p. s.*	*Miles.*	*m. p. h.*	*m. p. h.*
10,000	36	— 2	6.21	80	— 4
7,500	34	— 2	4.66	76	— 4
5,000	26	— 1.5	3.11	58	— 3
3,000	20	— 1	1.86	45	— 2
1,000	8	— 1	0.62	17	— 2
Surface	4	— 0.5	Surface	9	— 1

Two points may be noted in passing: (1) The eastward drift seems to be stratified into a series of steps by a decided change of the eastward velocity, and it appears that some form of stratus cloud is to be found at the bottom, and some form of cumulus cloud at the top, of each distinct stratum of flowing air. This indicates that at the surface of discontinuity between moving strata, the stratus type of cloud forms by a process of cooling through mixture from adjacent layers of air at different temperatures, which is in accord with general theory. It also shows that the cumulus clouds form by vertical convection and dynamic cooling within a stratum having about the same uniform velocity of motion throughout its mass and this is also theoretically correct. (2) The components of average total motion do not show that the atmosphere drifts northward in the higher levels and at the surface, and southward in the lower middle levels, somewhat elevated from the ground, as was claimed should be the case by Professor Ferrel in his canal theory of the general circulation of the atmosphere. I will return to this topic and consider it at length, but the fact here indicated is that the observations do not sustain that part of the general canal theory. It is becoming clearly demonstrated to students that the circulation of the air is a more complicated problem than the early meteorologists assumed, and in consequence it will be necessary to study in detail the stream lines over the several continents and oceans, find out their local characteristics, and after that try to combine them in a large comprehensive scheme.

DESCRIPTION OF THE CIRCULATION OVER HIGH AND LOW AREAS.

Figs. 6 and 7 represent the adjusted mean vectors of direction and velocity of motion in high and low areas, as derived from the Weather Bureau observations of 1896-97. They are based upon about 6,000 theodolite observations made at

Washington, D. C., and about 25,000 nephoscope observations made at 15 stations distributed quite uniformly over the territory east of the Rocky Mountains. They give only a mean or average scheme of the circulation and are necessarily somewhat idealized, as regards the movements of the air in individual configurations, since they include all the anticyclones and cyclones of the cloud year, many of which were only imperfectly developed, and could not have agreed with the best types that might have been selected. In order that no false impressions should remain with students concerning the actual circulation of the atmosphere, because of this construction of a well-balanced type, I compiled for the International Cloud Report a series of composite charts, Nos. 20 to 35, inclusive, which show the actual stream lines in high and low areas over the several areas of the United States, both for summer and winter. These charts are not only interesting, but they are very valuable, because they give the normal flow of the air when the anticyclonic and cyclonic centers are located in different parts of the country. They ought to be studied carefully by every forecaster, and the general knowledge given by the charts should be kept firmly in mind when considering the meaning of the individual daily weather maps, as they will guide the judgment to safer conclusions than would be possible without them. For the student of theoretical meteorology they are indispensable, because they correct the impressions which may be given by a contemplation of the figs. 6 and 7, or by reflecting upon the analytical formulæ.

DISCUSSION OF THE VECTORS IN HIGH AREAS.

The area about the center of circulation was subdivided into twenty small parts, numbered as already described in a previous paper; the upper left-hand plans of figs. 6 and 7 show them again for convenience of reference. Through the center of each of the three concentric groups a circle is drawn in dotted lines, and these are marked I, II, III, their distance from the center being 250, 750, 1,250 kilometers, respectively. The adopted heights of the planes of motion in meters and miles are written on each level, also the normal velocity vector in meters per second (m. p. s.), and miles per hour (m. p. h.). The scale of distances is 1 cm. = 500 kilometers, and the scale of velocities is 1 mm. = 2 meters per second; the latter can be reduced to miles per hour by multiplying with the factor 2.24. The left-hand plans contain the total vector as observed in the atmosphere; the right-hand plans give the component vector, which, combined with the normal vector, produces the observed vector, using the rule of the parallelogram of vectors. Each vector has been carefully constructed and deserves considerable confidence. The smoothly balanced configuration in each level and the gradual change which occurs in passing from one level to another show that this represents a natural and easy form of flow for the atmosphere, so that the motion will occur without sharp changes. The figures speak plainly for themselves, and only a few words are required regarding the distinguishing features. In the high areas the total flow diminishes in strength from 10,000 meters to the surface; it has a slight curvature northward over the center in the highest level, but this concavity of the curves gradually increases till in the lower levels and at the surface the sinuous lines are converted into anticyclonic gyrations. The vectors north of the center are longer than those south of it from the top to the bottom. There is, however, a strong eastward drift in all levels, inward on the west side and outward on the east side, which is never overcome.

Passing now to the anticyclonic component vectors, it is noted that there is a remarkable symmetry in the configuration from the highest level to the lowest, taken as a whole. There are, however, two special features to be observed: (1) In the central areas, I, the flow is inward on the highest level, more from the north, however, than from the south; it is tangential on the middle level; and it is outward in the lowest level. This indicates a type of true vortex motion, which prevails at the center of anticyclones, and by it the air is drawn in at the top and discharged at the bottom of the vortex tube. (2) On the middle areas, II, the flow is nearly tangential throughout the entire series of strata, but on the outer areas, III, the vectors are pointed slightly outward from the top to the bottom, though more strongly on the east side than on the west side. There is, furthermore, the special feature that at the south or southwest side of the anticyclonic area, near the place marked *A*, a distinct discontinuity occurs in the vectors, by which on the west side an inflow from the south takes place, and on the east side an outflow from the north is indicated. I interpret these two facts together to mean that in the southeast quadrant there is a tendency for a heavy stream of the general circulation from the northwest to divide, so that a large portion moves to the south side of the adjacent cyclonic area and a small portion curls westward about the center of the high area. Also, on the west side of the high area a stream from the south divides, part flowing over the north of the high area and another part curling about the north side of the center of the adjacent low area. Fig. 9, Curling of the northward and southward streams about the centers of high and low areas, gives an idea of this process, especially in the strato-cumulus level, or at about 3,000 meters elevation. The heavy broken line represents the resulting sinuous eastward flow at that level. In the flow of fluids a wave motion, when the velocity exceeds a given amount, collapses and reappears in the form of whirls of discontinuous surfaces along the sides. Something of this sort is apparently operating in this connection.

We observe that in the 3,000-meter level the anticyclonic vectors are stronger than in the levels above or below, the diminution toward the surface being greater than toward the higher levels. The superposition of the component gyration upon the eastward drift is distinct and even vigorous at 10,000 meters, and hence it is inferred that the disturbance of the atmosphere in high areas extends to at least 6 or 8 miles, though only as a small deflection of the eastward drift in the upper strata.

DISCUSSION OF VECTORS IN LOW AREAS.

The vectors in the low areas should in general be a little longer than those in the high areas. In nature the highs cover a larger territory than do the lows, but as the amount of air which streams through each of them is probably about the same, it would require a greater velocity in the lows to produce an equal discharge through them. The vectors flow southward relatively to the center, and they are larger on the southern side than on the northern. The connection of the streams between the high and low areas is shown by the smooth flow of the two sets of vectors on their eastern and western sides, respectively. The stream lines are convex upward, and the curvature increases from the 10,000-meter level to the surface. In the 1,000-meter level the gyratory movement nearly supersedes the sinuous or wave-like flow, but the vectors on the north side are not entirely reversed to the westward.

The cyclonic components are very symmetrically formed throughout the entire stratum of air that has been examined. They have the following characteristic, namely, that from the surface to the 10,000-meter level the vectors have an inflow toward the center, except in a few subareas marked with the letter A. It is noted that from the 10,000-meter level to the 1,000-meter level, near the place A, the vectors are almost exactly opposed to each other in direction, those on the east side flowing outward and those on the west side flowing inward. This divergence of direction indicates that a stream flows from the north to the south on the west of the low area, and that an independent stream flows northward on the east side of the low area, something in the manner suggested on fig. 9. The

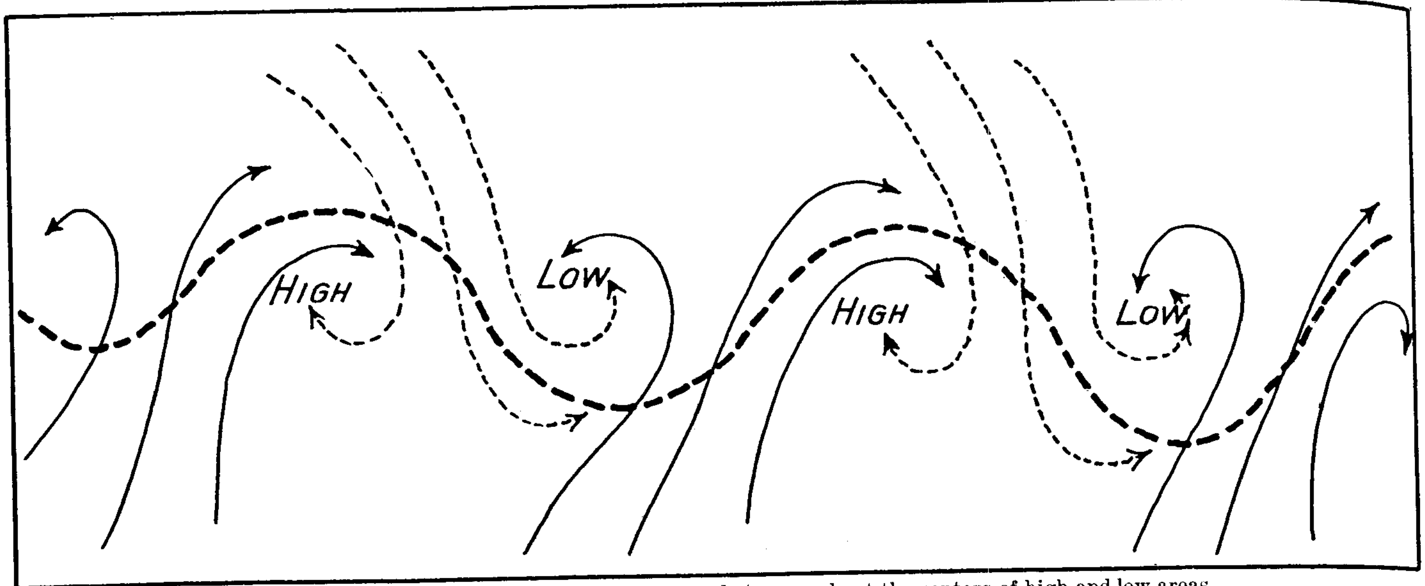


FIG. 9.—Curling of the northward and southward streams about the centers of high and low areas.

separate streams from the north and from the south coalesce on the south side of the center of the low area, as they do on the north side of the high area, but the two streams have an origin *outside* the areas of high and low pressure, respectively. Furthermore, it is noted that while in the high area the position of the point *A* is nearly stationary in all the strata mapped out, on the contrary it rotates nearly 90° from the east of north at the surface to the north of west in the highest stratum. The stream of warm air from the south curls around toward the west as it ascends from the surface to the upper levels, making a quarter of a helical revolution in an ascending spiral. The length of the vectors is greatest in the 3,000-meter level, 2 miles above the ground, and the vectors become gradually shorter upward and downward, diminishing more rapidly toward the surface. This agrees with the system of vectors in high areas, and shows that the influence of the cyclone extends above the 10,000-meter level, where it still deflects considerably the eastward drift, though it is most vigorous in the 3,000-meter level. The length of the vectors increases gradually from the III-areas to the I-areas, and averages about twice as long in the latter as in the former. In the anticyclonic components the III-vectors are even longer than the I-vectors, and they do not have any agreement with the simple vortex law $\varpi \omega =$ constant, where ϖ is the radial distance from the axis of rotation, and ω the angular velocity.

In the cyclonic components the I-vectors are longer than the III-vectors, but they fall short of exact conformity with the pure vortex theory. The entire flow suggests, therefore, the conflict of two counterflowing, horizontal streams which tend to produce vertical rotation, but in fact fail to reach this ideal, except possibly in highly developed cases of severe storms. There is no evidence that these motions are primarily

TABLE 9.—*Rectangular and cylindrical coordinates in high areas.*

Direction from center.	Area number.	10,000 meters. u_1	v_1	u_2	v_2	7,500 meters. u_1	v_1	u_2	v_2	Distance from center.
S	1	− 2	+29	− 2	− 6	+ 2	+24	+ 2	−10	
E	2	+ 6	+31	− 4	− 6	+ 8	+30	− 4	− 8	I. 250 km.
N	3	+ 6	+40	− 6	− 5	+ 6	+36	− 6	− 2	
W	4	+ 4	+39	− 3	+ 5	− 4	+32	+ 2	− 4	
S	5	+ 8	+28	+ 8	− 8	0	+24	0	−10	
SE	6	+10	+30	+ 2	− 9	+ 8	+30	+ 3	− 9	
E	7	+ 7	+40	+ 4	− 7	+ 8	+36	+ 2	− 8	
NE	8	+ 6	+43	+ 2	− 7	+ 8	+38	− 4	− 8	II. 750 km.
N	9	+ 2	+44	+ 2	− 8	+ 4	+40	− 4	− 6	
NW	10	− 4	+40	− 2	− 6	− 8	+38	+ 4	− 8	
W	11	− 4	+36	− 1	− 4	−10	+30	+ 4	−10	
SW	12	− 5	+28	0	− 7	− 8	+30	− 4	− 8	
S	13	+ 8	+30	+ 8	− 6	+ 4	+24	+ 4	−10	
SE	14	+ 9	+28	+ 2	− 9	+ 6	+28	0	− 9	
E	15	+ 9	+40	+ 4	− 9	+10	+38	+ 4	−10	
NE	16	+10	+42	− 4	−10	+ 9	+40	− 4	− 8	III. 1,250 km.
N	17	− 2	+44	+ 2	− 8	+ 3	+42	− 3	− 8	
NW	18	− 8	+40	+ 4	− 8	− 6	+40	+ 1	− 8	
W	19	− 8	+32	+ 4	− 8	− 9	+30	+ 4	− 9	
SW	20	− 8	+32	− 4	− 6	− 8	+28	− 6	− 8	

TABLE 10.—*Rectangular and cylindrical coordinates in low areas.*

Direction from center.	Area number.	10,000 meters. u_1	v_1	u_2	v_2	7,500 meters. u_1	v_1	u_2	v_2	Distance from center.
S	1	−10	+46	−10	+10	− 6	+46	− 6	+12	
E	2	−12	+34	− 2	+12	−12	+32	− 2	+12	I. 250 km.
N	3	− 4	+32	+ 4	+ 4	− 6	+26	+ 6	+ 8	
W	4	− 6	+40	− 6	− 4	+ 4	+44	−10	+ 4	
S	5	− 8	+44	− 8	+ 8	−10	+44	−10	+10	
SE	6	−12	+42	− 5	+14	−12	+34	− 6	+10	
E	7	−10	+32	− 4	+10	−10	+30	− 4	+10	
NE	8	− 4	+24	− 4	+12	− 6	+26	− 4	+ 9	II. 750 km.
N	9	− 6	+32	+ 4	+ 6	− 4	+28	+ 4	+ 6	
NW	10	− 3	+30	+ 6	+ 3	+ 4	+26	+ 4	+ 8	
W	11	+ 6	+44	− 6	+ 8	+ 8	+42	− 8	+ 8	
SW	12	+ 2	+46	− 6	+ 8	0	+46	− 7	+10	
S	13	− 4	+44	− 4	+ 8	− 4	+42	− 4	+ 8	
SE	14	− 8	+40	− 4	+ 8	− 8	+38	− 4	+ 8	
E	15	− 6	+36	0	+ 6	− 8	+30	− 4	+ 8	
NE	16	− 4	+28	− 4	+ 8	− 8	+28	+ 2	+10	III. 1,250 km.
N	17	− 4	+30	+ 4	+ 6	− 4	+30	+ 4	+ 4	
NW	18	− 4	+30	+ 6	+ 4	− 2	+28	+ 6	+ 2	
W	19	+ 6	+42	− 6	+ 6	+ 6	+40	− 6	+ 6	
SW	20	+ 4	+42	− 4	+ 6	+ 4	+40	− 2	+ 7	

ABLE 9.—*Rectangular and cylindrical coordinates in high areas*—Cont'd.

Direction from center.	Area number.	5,000 meters. u_1	v_1	u_2	v_2	3,000 meters. u_1	v_1	u_2	v_2	Distance from center.
S	1	+2	+18	+2	−8	+4	+12	+4	−8	I. 250 km.
E	2	+8	+22	−2	−8	+8	+16	−4	−8	
N	3	+4	+34	−4	−8	−2	+26	+2	−6	
W	4	−8	+28	−2	−8	−8	+16	+4	−8	
S	5	+4	+16	+4	−10	+6	+14	+6	−6	II. 750 km.
SE	6	+8	+20	+4	−8	+12	+14	+4	−12	
E	7	+8	+28	+2	−8	+10	+20	0	−10	
NE	8	+6	+32	0	−8	+6	+28	+2	−10	
N	9	+3	+34	−3	−8	−2	+28	+2	−8	
NW	10	−6	+30	+1	−7	−8	+24	+2	−10	
W	11	−8	+24	+2	−8	−8	+24	−4	−8	
SW	12	−6	+20	0	−8	−6	+14	−4	−8	
S	13	+4	+16	+4	−10	+8	+10	+8	−10	III. 1,250 km.
SE	14	+8	+22	+4	−8	+10	+16	+5	−11	
E	15	+8	+30	+4	−8	+10	+26	+6	−10	
NE	16	+7	+32	0	−10	+10	+28	−2	−12	
N	17	0	+36	0	−10	+2	+30	−2	−10	
NW	18	−9	+32	+1	−11	−12	+24	+4	−12	
W	19	−10	+24	+2	−10	−10	+24	−4	−10	
SW	20	−8	+22	−4	−8	−8	+14	−4	−10	

Direction from center.	Area number.	1,000 meters. u_1	v_1	u_2	v_2	Surface. u_1	v_1	u_2	v_2	Distance from center.
S	1	+4	+2	+4	−6	+3	0	+3	−4	I. 250 km.
E	2	+6	+12	+4	−6	+3	+7	+3	−3	
N	3	−6	+14	+6	−6	−4	+7	+4	−3	
W	4	−8	+6	+2	−8	−5	+2	+2	−5	
S	5	+8	+4	+8	−4	+3	+1	+3	−3	II. 750 km.
SE	6	+10	+6	+6	−8	+4	+2	+4	−4	
E	7	+8	+10	+2	−8	+6	+8	+4	−6	
NE	8	+6	+16	+6	−8	+4	+10	+2	−7	
N	9	−4	+16	+4	−8	−3	+10	+3	−6	
NW	10	−8	+10	+1	−9	−5	+8	0	−6	
W	11	−10	+8	0	−10	−6	+2	+2	−6	
SW	12	−8	+2	−2	−10	−3	0	+2	−5	
S	13	+8	0	+8	−8	+4	−1	+4	−5	III. 1,250 km.
SE	14	+10	+4	+6	−9	+7	+5	+6	−4	
E	15	+8	+14	+6	−8	+6	+9	+5	−6	
NE	16	+8	+16	+2	−11	+4	+10	+2	−7	
N	17	−4	+18	+4	−10	−4	+8	+4	−4	
NW	18	−10	+12	+4	−10	−6	+8	+1	−7	
W	19	−10	+10	−2	−10	−7	+4	0	−7	
SW	20	−10	+4	−4	−10	−5	−1	−2	−5	

$+u_1$ = southward. $+u_2$ = radial outward.
$+v_1$ = eastward. $+v_2$ = tangential counter clockwise.

TABLE 10.—*Rectangular and cylindrical coordinates in low arean*—Cont'd.

Direction from center.	Area number.	5,000 meters. u_1	v_1	u_2	v_2	3,000 meters. u_1	v_1	u_2	v_2	Distance from center.
S	1	−10	+42	−10	+16	−10	+40	−10	+20	I. 250 km.
E	2	−16	+22	−4	+16	−18	+16	−4	+18	
N	3	−2	+16	+2	+10	−8	+12	+8	+6	
W	4	+14	+28	−6	+14	+16	+28	−8	+16	
S	5	−4	+36	−4	+10	−10	+32	−10	+12	II. 750 km.
SE	6	−14	+32	−5	+14	−12	+26	−6	+12	
E	7	−12	+24	−2	+12	−14	+24	−4	+14	
NE	8	−10	+20	+4	+12	−12	+12	+4	+14	
N	9	−10	+18	+6	+10	−12	+14	+6	+12	
NW	10	+12	+20	−6	+12	+12	+18	−7	+10	
W	11	+12	+30	−4	+12	+16	+22	−2	+16	
SW	12	+4	+38	−4	+12	+12	+32	0	+18	
S	13	−4	+32	−4	+6	−6	+28	−6	+8	III. 1,250 km.
SE	14	−6	+30	−4	+6	−8	+26	−2	+10	
E	15	−8	+22	−4	+8	−10	+18	−2	+10	
NE	16	−6	+22	+2	+7	−10	+14	+4	+10	
N	17	−8	+20	+6	+8	−12	+14	+12	+6	
NW	18	+6	+22	−2	+7	+10	+18	−6	+8	
W	19	+8	+28	−2	+8	+12	+24	−4	+12	
SW	20	+4	+34	−4	+8	+4	+28	−4	+8	

Direction from center.	Area number.	1,000 meters. u_1	v_1	u_2	v_2	Surface. u_1	v_1	u_2	v_2	Distance from center.
S	1	−6	+24	−6	+16	−4	+10	−4	+6	I. 270 km.
E	2	−8	+4	−4	+8	−6	0	−4	+6	
N	3	+10	+4	−10	+4	+4	−2	−4	+6	
W	4	+10	+12	−4	+10	+8	+8	−4	+8	
S	5	−4	+20	−4	+12	−4	+10	−4	+5	II. 750 km.
SE	6	−10	+12	−4	+10	−6	+6	−2	+6	
E	7	−10	+6	−2	+10	−6	+2	−2	+6	
NE	8	−10	+8	+8	+6	−4	−2	−2	+4	
N	9	+10	+4	−10	+4	+4	−2	−6	+4	
NW	10	+12	+4	−6	+10	+6	+2	−4	+5	
W	11	+8	+14	−6	+8	+6	+8	−4	+6	
SW	12	+8	+20	−4	+14	+4	+10	−2	+8	
S	13	−4	+18	−4	+10	−4	+8	−4	+4	III. 1,250 km.
SE	14	−10	+10	−2	+10	−6	+4	−4	+4	
E	15	−8	+8	0	+8	−6	+4	0	+6	
NE	16	−8	+10	+8	+4	−4	−2	−2	+4	
N	17	+10	+6	−10	+2	+4	−2	−6	+4	
NW	18	+10	+8	−9	+4	+6	0	−4	+6	
W	19	+8	+14	−6	+8	+6	+8	−4	+6	
SW	20	+6	+14	0	+8	+3	+8	−2	+5	

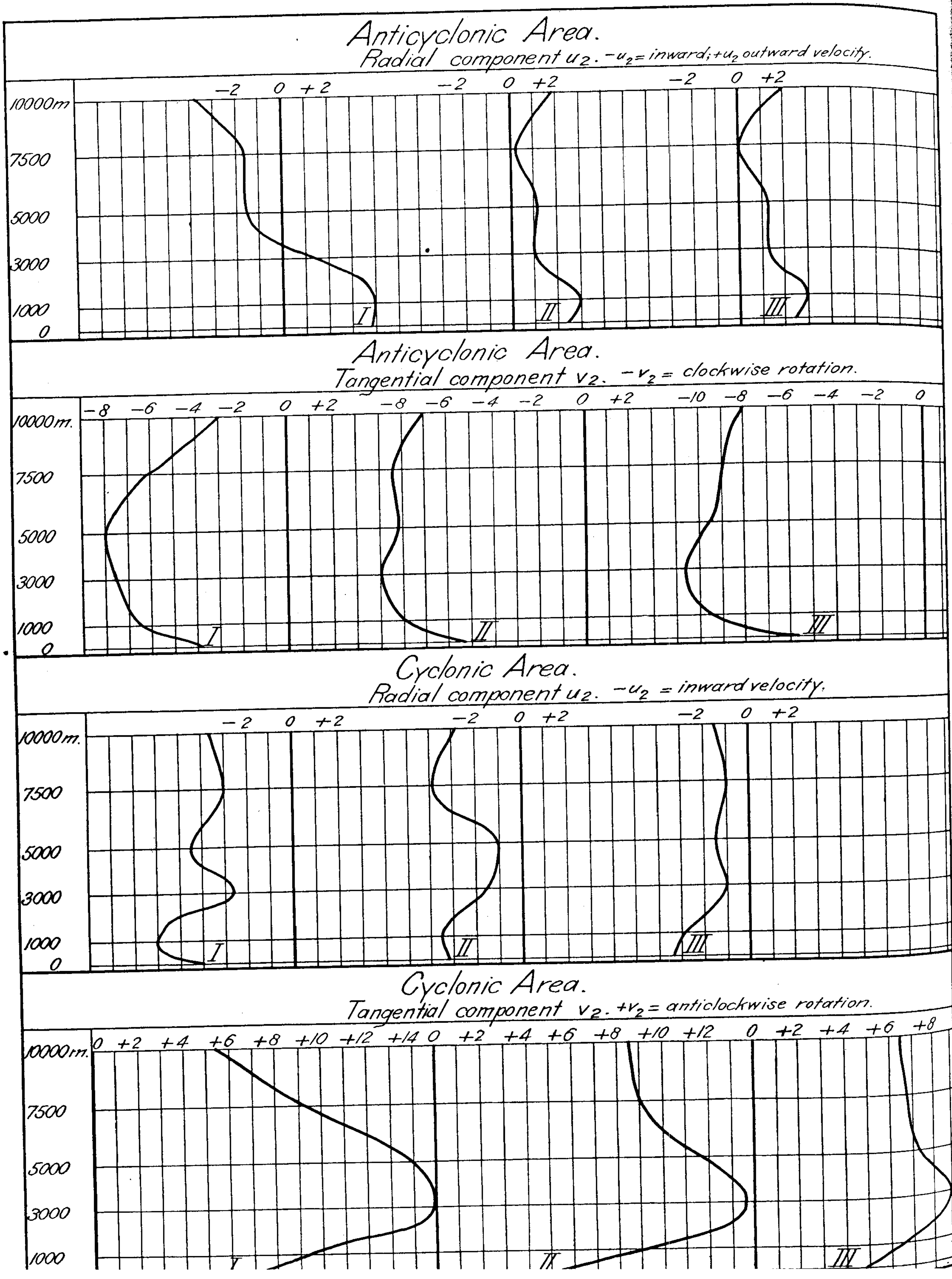
$+u_1$ = southward. $+u_2$ = radial outward.
$+v_1$ = eastward. $+v_2$ = tangential counter clockwise.

le to vertical convective currents developed through the local ating or cooling of restricted areas near the center of the cy- nic and anticyclonic areas, respectively. It is evidently de- able to avoid extreme statements in this connection, because study of the motions of the atmosphere shows that nearly ery possible type of motion from the counterflow of opposing rizontal streams to the pure vortex due to an ascending helix y occur, and yet the present compilation indicates that the rmer is the average type to which the stream lines conform the extra-tropical circulation of the United States.

THE NUMERICAL VALUES OF THE VECTORS.

In order to bring out these facts a little more clearly, the vectors of fig. 6 have been translated into the numerical values of Table 9, Rectangular and cylindrical coordinates in high areas; and those of fig. 7 into the numbers of Table 10, Rectangular and cylindrical coordinates into low areas. These tables need no further explanation in this connection, after what has been already stated.

Table 11, Mean components on the I, II, III circles in meters



Anticyclonic Area.
Radial component u2. −u2 = inward; +u2 outward velocity.
−2 0 +2
10000m
7500
5000
3000
1000
0
I
II
III
Anticyclonic Area.
Tangential component v2. −v2 = clockwise rotation.
−8 −6 −4 −2 0 +2
−10 −8 −6 −4 −2 0
Cyclonic Area.
Radial component u2. −u2 = inward velocity.
Cyclonic Area.
Tangential component v2. +v2 = anticlockwise rotation.
0 +2 +4 +6 +8 +10 +12 +14

per second and in miles per hour, is derived from the anticyclonic components of Table 9, and the cyclonic components of Table 10, by taking the arithmetical mean of the I-areas (1–4), the II-areas (5–12), and the III-areas (13–20). These means give the average value of the motion, though we, of course, depart from the perfectly natural condition by the summation. Thus in the anticyclonic areas for the radial component u_2 there is an inflow at the top of I-areas, and an outflow at the bottom; and a gentle outflow in the II-areas and III-areas from the top to the bottom. Also compare fig. 10, where the results of Table 11 are plotted. The tangential component v_2 is stronger throughout the middle strata than in those which are higher or lower, but it is much more vigorous in the III-areas than in the I-areas especially at the 3,000-meter level. In the cyclonic areas the radial component u_2 increases generally from the III-area to the I-area. There is a little irregularity in the changes of this component probably due to imperfections in my vector system. The tangential component v_2 increases rapidly from the III-areas to the I-areas, and remarkably so at the 3,000-meter level.

TABLE 11.—*Mean components on I, II, III circles.*

ANTICYCLONIC COMPONENTS.

Distance from center.	I. 250 kilometers.		II. 750 kilometers.		III. 1,250 kilometers.	
Meters per second.	u_2	v_2	u_2	v_2	u_2	v_2
H=10,000	−3.8	−3.0	+1.9	−7.0	+2.0	−8.0
7,500	−1.5	−6.0	+0.1	−8.4	0.0	−8.8
5,000	−1.5	−8.0	+1.3	−8.1	+1.4	−9.4
3,000	+1.5	−7.5	+1.0	−9.0	+1.4	−10.6
1,000	+4.0	−6.5	+3.1	−8.1	+3.0	−9.5
0	+3.0	−3.8	+2.5	−5.4	+2.5	−5.6
CYCLONIC COMPONENTS.						
H=10,000	−3.5	+5.5	−2.9	+8.6	−1.5	+6.5
7,500	−3.0	+9.0	−3.9	+8.9	−1.0	+6.6
5,000	−4.5	+14.0	−1.9	+11.8	−1.5	+7.3
3,000	−3.5	+15.0	−2.4	+13.5	−1.0	+9.0
1,000	−6.0	+9.5	−3.5	+9.3	−2.9	+6.8
0	−4.0	+6.5	−3.3	+5.5	−3.3	+4.9

ANTICYCLONIC COMPONENTS.

Distance from center.	I. 155 miles.		II. 466 miles.		III. 777 miles.	
Miles per hour.	u_2	v_2	u_2	v_2	u_2	v_2
H=10,000	−8.5	−8.7	+4.3	−15.7	+4.5	−17.9
7,500	−3.4	−13.4	+0.2	−18.8	0.0	−19.7
5,000	−3.4	−17.9	+2.9	−18.1	+3.1	−21.0
3,000	+3.4	−16.8	+2.2	−20.1	+3.1	−23.7
1,000	+8.9	−14.5	+6.9	−18.1	+6.7	−21.3
0	+6.7	−8.5	+5.6	−12.1	+5.6	−12.5
CYCLONIC COMPONENTS.						
H=10,000	−7.8	+12.3	−6.5	+19.2	−3.4	+14.5
7,500	−6.7	+20.1	−8.7	+19.9	−2.2	+14.8
5,000	−10.1	+31.3	−4.3	+26.4	−3.4	+16.3
3,000	−7.8	+33.6	−5.4	+30.2	−2.2	+20.1
1,000	−13.4	+32.4	−7.8	+20.8	−6.5	+15.2
0	−8.9	+14.5	−7.4	+12.3	−7.4	+11.0

It has been taught in the common expositions of the canal theory of the general circulation that there exists in middle latitudes a strong northward component in the upper strata, a strong southward component in the surface and lower strata, and a powerful eastward component in all strata, increasing from the ground upward. It can be seen by inspecting figs. 6 and 7 that while there is everywhere a general eastward drift, there are certain subareas over which especially a northward component prevails, and others over which there is a southward component. In order to find the maximum meridional components it is expedient to select the following areas for the northward component: Low (16, 8, 2, 7, 15, 6, 14) and High (18, 10, 11, 19, 12, 20), and for the southward component High (16, 8, 2, 7, 15, 6, 14) and Low (18, 10, 4, 11, 19, 12, 20). The values of u_1, v_1 are taken for these areas from Tables 9 and 10, and the mean of them is given in Table 12, Northward and southward velocities in selected areas. It can be seen at once that the general canal theory is by no means supported by the observations. The fact seems to be that between the high and low centers, west of the high and east of the low, there is a northward current in all levels, strongest at about the 3,000-meter level, while east of the high and west of the low there is a southward current also strongest in the same level. The interchange of air between the pole and the Tropics appears, therefore, to be brought about by alternate currents in middle latitudes flowing past each other on the same levels, and not over each other at entirely different levels, as the canal theory requires. The thermal equilibrium of the air is, therefore, restored through the anticyclonic and cyclonic mechanism, and not by the overflowing currents from the Tropics to the poles and underflowing currents from the poles to the Tropics, as commonly taught. This profoundly modifies the canal theory of the general circulation of the atmosphere and introduces us to a new point of view. The discussion of the theories of the circulation of the air as explained by Ferrel, Oberbeck, and other meteorologists must be taken up next in order, and their views contrasted with the results of our observations.

TABLE 12.—*Northward and southward velocities in selected areas.*

Height of the stratum.	Northward.		Southward.	
	L. 16, 8, 2, 7, 15, 6, 14. H. 18, 10, 4, 11, 19, 12, 20.		H. 16, 8, 2, 7, 15, 6, 14. L. 18, 10, 4, 11, 19, 12, 20.	
	u_1	v_1	u_1	v_1
10,000	−6.4	+34.5	+4.4	+37.7
7,500	−8.4	+31.9	+5.8	+36.2
5,000	−9.1	+25.2	+8.1	+27.6
3,000	−10.3	+19.7	+10.6	+22.7
1,000	−9.2	+7.9	+8.4	+11.7
Surface	−5.2	+2.6	+5.3	+6.9

Compare Table 124, International Cloud Report, p. 606.

FOG AND FROST FORMATION.

By DAVID CUTHBERTSON, Local Forecast Official.

An unusually dense fog, such as had not been observed for many years, occurred at Buffalo, N. Y., during the night of February 15 to 16, 1902. It was so remarkable for its great density and for the beautiful frostwork which formed on all sides of trees and other objects that it was a very common topic of conversation for days, and the local Weather Bureau the highest was 84°, at Fort Laramie on the 19th and 20th, and the lowest, zero, at Daniel on the 1st. The average precipitation was 1.19, or 0.48 below normal; the greatest monthly amount, 2.24, occurred at Red Bank, and the least, 0.10, at Centennial.

Plowing and seeding were in progress during the month over much of the State, but cold, freezing weather delayed the work. The cold rain and snow on the 21st and 22d was severe on sheared sheep, and many perished during the storm.—*W. S. Palmer.*

SPECIAL CONTRIBUTIONS.

STUDIES ON THE STATICS AND KINEMATICS OF THE ATMOSPHERE IN THE UNITED STATES.

By Prof. Frank H. Bigelow.

IV.—REVIEW OF FERREL'S AND OBERBECK'S THEORIES OF THE LOCAL AND THE GENERAL CIRCULATIONS.

GENERAL COMPARISON OF FERREL'S AND OBERBECK'S THEORIES.

In order to discuss the theories which have been proposed to account for the circulation of the atmosphere in cyclones and anticyclones, and in general over an hemisphere of the earth, it will be convenient to confine our attention to the views propounded by Ferrel and Oberbeck because their treatment is quite complete, and also because they represent a large number of writers who agree with them more or less perfectly. There is another theory of quite a different type which can be taken up profitably after some critical remarks have been made on the validity of these earlier views. In their treatment of the general circulation of the atmosphere both Ferrel and and Oberbeck adopt the "canal theory" of the circulation, and work out their solutions along that line. Oberbeck places his origin of coordinates at the center of the rotating earth, develops the equations of motion, and transforms to the surface when they are employed in the evaluation of the resulting velocities. He also deduces the terms in the pressure due to the absolute motion of the earth, and to the relative motions of the atmosphere. Ferrel places his origin of coordinates at the surface of the earth, transforms his equations to include a temperature term through the variations of the density, and discusses the meaning of the equations under special limitations, with illustrations from the observed motions of the atmosphere. It may be remarked that von Helmholtz introduces the temperature terms into the equations of motion, not through the density, but through the pressure, by using the equation of elasticity, $p\ v = R\ T$. This procedure is probably a better method of solution. There is not much difference in the results as derived from the analysis by these authors, but there is serious difficulty in making them agree with the modern observations of the motions of the atmosphere in the higher strata, as determined by the international cloud work.

In their treatment of the cyclone Ferrel and Oberbeck diverge radically from each other, though they start with the same physical principle, namely, a local overheated mass of air which in rising through its own buoyancy produces the cyclonic circulation. Ferrel assumes a fixed cylindrical boundary about his cyclone, and considers a warm-center cyclone (circulation anticlockwise), surrounded by a pericyclonic ring (circulation clockwise), in the Northern Hemisphere, the two portions being separated by a surface where the gyratory velocity vanishes. By maintaining a cold mass of air in the center instead of a warm mass the circulation is reversed, and a cold-center cyclone is developed. Oberbeck does not assume any external boundary to the circulating mass of air, but in the central region, bounded by a cylindrical surface, there is a vertical component, while outside of it there is no such vertical ascent of the air. At this boundary there is a discontinuity in the vertical velocity, and at the same distance from the center the gyratory velocity about the axis is a maximum; this falls away to zero at the center and also at some indefinite distance in the outer region. It is essential to the existence of these two theories, although they differ so radically from each other, to establish the fact that such local centers of heated air in the warm-center cyclones do occur in nature, for without them these two theories entirely fail of applicability to our meteorology. They are both possible forms of vortex motion, but it is necessary to show that the antecedent physical conditions prevail, before they can be accepted as explanations of the observed cyclonic motions.

Both of these authors have experienced much difficulty in accounting for the anticyclones. Ferrel explained that the interference of two of his pericyclonic rings would heap up the air and produce an area of high pressure with a clockwise outflow, but this theory is so far from being in conformity with the facts, that it is now, by general consent of meteorologists, considered to be of only historical value. Oberbeck sought, by simply reversing the sign of the vertical component of velocity, to invert his cyclone into an anticyclone. He met with a stumbling-block in the mathematical analysis, but was relieved of this by Pockels, who correctly evaluated the constant of integration. No attempt was made to show that the resulting stream lines conform to the motions of the air in high areas of pressure. Indeed, since the modern observations have given us more correct lines of flow, it is quite certain that the anticyclone can not be explained in this way.

THE SUPPLY OF LOCAL CENTERS OF HEAT.

It is evident, therefore, that the first practical question to decide is whether such local masses of air exist, heated in the under strata and more or less cylindrical in form, as will produce either of the above forms of cyclone. Meteorologists have generally supposed that this is the case, and they have usually attributed the source of the vertical convection to the latent heat of condensation. Dr. J. Hann, in 1890, and again in his Lehrbuch der Meteorologie, has shown in great detail the inadequacy of this source of heat to produce cyclones, and he has indicated that the source of cyclonic action consists rather in horizontal convection currents. As this agrees with the view which I have already advocated, since it seems to me to be in conformity with the observations, I will therefore make a résumé of my remarks on this topic in the International Cloud Report. It will be a great gain if meteorologists can be persuaded to reject the old condensation theory, which has an apparent but really illusory plausibility, in favor of the really efficient source of dynamic action contained in the long, horizontal currents which flow between the Tropics and the polar regions in the middle strata of the atmosphere, as illustrated in the preceding Paper III.

There is, in fact, a fundamental difficulty in accounting for the local supply of heat which is assumed to set the vertical convection in operation. Ferrel himself doubted the efficiency of the latent heat of condensation, for he says in his Meteorological Researches, Appendix No. 10, United States Coast and Geodetic Survey, Part II, page 201: "The condensation of aqueous vapor, therefore, plays an important part in cyclonic disturbances, but is by no means a primary or a principle cause of cyclones." Professor Loomis asserted in Silliman's Journal, July, 1877: "Rainfall is not essential to the formation of areas of low barometer, and is not the principle cause of their formation or of their progressive motion." Indeed, a reasonable familiarity with the United States weather maps proves conclusively that there are many deep, fully-developed storms which form near the north Pacific coast and advance to the Gulf of St. Lawrence without any precipitation worth mentioning. Also, cyclones form frequently in the southern Rocky Mountain districts and advance into the lower Mississippi Valley without any important rainfall; from that region onward in their course the precipitation and intensity of the storm often greatly increase, since the latent heat derived from the inflowing moist air of the Gulf of Mexico undoubtedly assists the vertical convection in the center of the cyclone. If the horizontal currents which converge upon a cyclonic center are bearers of moisture, the vertical motion caused by the dynamic action condenses the aqueous vapor; but if such currents are dry, the cyclone advances unattended by precipitation. Hence, it follows that rainfall is a secondary phenomenon, and is not sufficient of itself to produce true cyclonic gyrations. There are, on the other hand, many cases of copious precipitation without any attendant low pressure. Thus, on the front of an advancing cold wave there is often a long band of rain area stretching from the Great Lakes to the Gulf of Mexico, but without cyclonic formation, the precipitation being in fact caused by the upward lift of a warm southerly current which overflows the wedge-shaped cold wave in its southward movement. This is a dynamic uplift by overflow, instead of by vortical gyration, and it is sufficient to cause condensation and precipitation by the mechanical action of an underflowing stratum of very low temperature. Furthermore, on one side of a mountain range, as the Alps, rainfall is observed to occur in the midst of the high pressure, while on the other side of the mountains the atmosphere is clear and the pressure is relatively low, thus reversing the required conditions. In the summer season, local thunderstorms are quite as likely to happen in the midst of an area of high pressure as in that of low pressure, but here the vertical convection distinctly exists and arises from a superheating of the lower strata. If buoyancy of the lighter air is the principal cause of the gyration of cyclones, then we should expect to find a similar rotatory motion developed in the formation of cumulus clouds and thunderstorms in hot summer weather, when the vertical component is evidently strong. But, on the contrary, while the ascension of the heated air is clearly visible in these clouds, there is usually no evidence of gyration of the cyclonic type. It has been found by Hann's mountain observations and by the Berlin balloon ascensions that the temperature of the central portions of the cyclone is colder than the temperature in the midst of the anticyclone at the same levels. Hence, if the relative density of the air column is the source of cyclonic gyration, we perceive that this fact is in direct contradiction to the requirements of the condensation theory, which demands that the central column of the cyclone shall be warmer than its surroundings.

Since the advocates of the condensation theory of cyclones usually regard the generation of the tropical hurricanes as the best example of that source of gyratory energy, it may be proper to state that the observed facts do not appear to sustain the theory. For (1) there is no evidence of a decided increase in the local temperature at the center of hurricanes. In this connection it is believed that the sudden rise in temperature in the Manila hurricane of October 20, 1882, was due to the direct radiation of the sun through the calm eye of the storm; (2) the winds are not sufficiently changed in direction at the feeble ring of high pressure to conform to the Ferrel pericyclone; they should be turned through at least 90° more in azimuth; (3) the conditions of heated, saturated air prevail in the Tropics throughout the year, but the hurricanes are produced at certain seasons only, and these are the times when the counter currents of the trades are most active at their northern and southern limits. Dr. Hann rejects the rain theory, and adopts the counter current theory for huricanes: Lehrbuch der Meteorologie, pp. 563–566. It can be proved conclusively from observations that two counter currents flow together at the places where tornadoes are formed, where the tropical hurricanes are generated, and also where the cyclones of the middle latitudes are produced. These currents are especially active in the strata one or two miles above the ground, and this is probably the reason why they have not received due attention in constructing the theory of storms. It may be concluded that the local overheated central region does not exist in cyclones as the chief cause of their motion and that the theories fail which depend upon it. There are, however, other serious difficulties of a mathematical nature to which attention must be directed.

FERREL'S LOCAL CYCLONE.

On page 595, and following, of the International Cloud Report, the fundamental formulæ and assumptions, as employed by Professor Ferrel in his discussion of the local cyclone are summarized, and an abstract for our purposes, in the notation already described in Paper II of this series, Monthly Weather Review, February, 1902, p. 81, is given in the following lines:

Cylindrical equations of motion applicable to the local circulation in cyclones. See International Cloud Report, p. 50[illegible]

185.
$$-\frac{1}{\rho}\frac{\partial P}{\partial \varpi} = \frac{du}{dt} - \left(2n\cos\theta + \frac{v}{\varpi}\right)v + ku.$$
$$-\frac{1}{\rho}\frac{\partial P}{\varpi\partial \varphi} = \frac{dv}{dt} + \left(2n\cos\theta + \frac{v}{\varpi}\right)u + kv.$$
$$-\frac{1}{\rho}\frac{\partial P}{\partial z} = \frac{dw}{dt} + g.$$

Assumptions made in duscussing these equations:

1. The temperature is a function of ϖ only, varies along the radius, but not with the altitude, and is symmetrical about the center.

2. The local cyclone is symmetrical about the axis of gyration, and is bounded by a cylindrical surface whose constant radius is ϖ_o.

3. The friction is proportional to the relative velocity of two adjoining strata.

4. The assumed law of the variation of temperature along the radius is as follows, the isotherms being circles about the center:

$$t = A_o + \frac{1}{2}(t_c - t_o)\cos\frac{\varpi}{\varpi_o}\pi.$$

5. In integrating for the law of the preservation of areas it is assumed that there is no friction between the air and the surface of the earth.

6. All forces depending upon the vertical velocity of the currents can be neglected, $w = 0$.

7. $P_o =$ the pressure for $h_o = 0$.

The equations of motions become the following by applying these assumptions and transforming the pressure term:

397b. (1.)
$$-\frac{\partial \log P_o}{a\partial\varpi} = \frac{du}{dt} - \left(2n\cos\theta + \frac{v}{\varpi}\right)v + ku - \frac{gh\,a}{\varpi_o(1+\alpha t)}\frac{1}{2}(t_c - t_o)\pi\sin\frac{\varpi}{\varpi_o}$$

(2.)
$$0 = \frac{dv}{dt} + \left(2n\cos\theta + \frac{v}{\varpi}\right)u + kv;$$

where $a = \frac{1}{gl(1+\alpha t)}$, by Table 64, 23; $t_c =$ temperature at the center; and $t_o =$ temperature at the outer boundary of the cyclone.

As the result of the discussion of these two equations Ferrel deduces his cyclone which is represented in fig. 11. The corresponding cold-center cyclone is shown in fig. 12.

The first of the above assumptions regarding the distribution of the local temperature does not sufficiently conform to the data on the weather maps to be satisfactory, because ıutheast section of a cyclone in the United States is usually ıuch warmer than the northwest section. The symmetrical stribution of pressure about the center, where $-\frac{1}{\rho}\frac{\partial P}{\varpi\partial\varphi}=0,$ found in highly developed cyclones, and may be admitted the analysis. The friction term is of minor importance with spect to the general theory of a cyclone which we are conlering, and the vertical force derived from w may be neg-›ted, though not the vertical velocity itself.

There are two entirely different methods of treating the ›ond equation of motion,

$$7\,b.\ (2.)\qquad \frac{dv}{dt}+\left(2n\cos\theta+\frac{v}{\varpi}\right)u+kv=0,$$

d this is the parting of the ways between (1) Ferrel's theory d (2) the German theory. The primary question to be kept mind is, does the result of the observations conform exactly either of these theories? This equation can be integrated omitting the friction term kv and *assigning an outer boundary;* it may be solved by a simple transformation, *since two roots ı be found*, and the discussion of the group of general equans of motion carried forward with these. The former method Ferrel's, and the latter is that of the German school, namely, ıldberg and Mohn, Sprung, Oberbeck, Pockels, and others.

FERREL'S SOLUTION.

Neglecting the friction term, the equation 397*b* (2) can be nsformed, by substituting $u=\frac{\partial\varpi}{\partial t}$ and multiplying by ϖ, o

$$2\,n\cos\theta\,.\,\varpi\frac{\partial\varpi}{\partial t}+\varpi\frac{dv}{dt}+v\frac{\partial\varpi}{\partial t}=0.$$

should be noted that $\frac{dv}{dt}=\frac{\partial v}{\partial t}+\frac{u\partial v}{\partial\varpi}+\frac{v\partial v}{\varpi\partial\varphi}$.

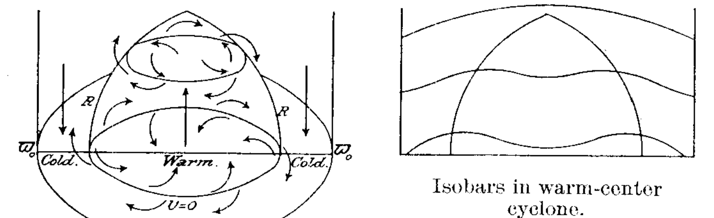
rrel integrates as if $\frac{dv}{dt}=\frac{\partial v}{\partial t}$, omitting the two other terms; eed, Ferrel was neglectful about the distinction between total and the partial differentials in several portions of work. The integration gives $\varpi^2\left(n\cos\theta+\frac{v}{\varpi}\right)=c$, for each ·ticle. Assigning an outer boundary ϖ_o as the limit of in-·ration, then, for the entire rotating mass, we deduce,

$$\varpi^2\left(n\cos\theta+\frac{v}{\varpi}\right)=\frac{1}{2}\varpi^2_o\,n\cos\theta;\ \text{and hence,}$$

$$v=\left(\frac{\varpi^2_o}{2\,\varpi^2}-1\right)\varpi\,n\cos\theta,$$

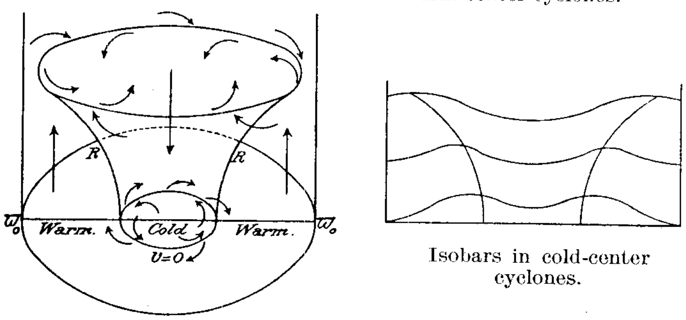
ere $v=$ the tangential velocity at the distance ϖ from the s of rotation. If $v=0$, $R=0.707\,\varpi_o$, where R is the radius the circle at which the gyratory velocity reverses its direcı. The locus of this R is indicated on fig. 11 for the warmter cyclone and on fig. 12 for the cold-center cyclone; these figures also show, in a general way, the circulation in this e of vortices. It will not be necessary to explain it further his connection, but it is especially important to observe that ·rel came to this vortex by the demands of his integration, l that he sought to uphold it by resorting to such physical rces of energy as seemed to be available. He had already ›lied an entirely similar process to his discussion of the cirıtion of the atmosphere of the earth over an entire hemis-·re, but in that case it was, at least in part, justified by the that the air on the hemisphere continues to remain the ıe mass, so that integration between the pole and the plane the equator was a proper procedure. Yet, in comparing vortex with the circulation as displayed in figs. 6 and 7 Paper III, we must consider the other objections besides difficulty of accounting for local supply of heat in the cenportions which is needed to keep the vortex in motion.

(1) Ferrel conceived the general cyclone on the hemisphere to be one with a cold center, since the poles are cold and the Tropics warm; and then the modification was made that the local cyclone is one with a warm center with the edges cooler than the middle portions. If a quantity of water be placed in a cylindrical vessel, and sawdust or some other material be scattered in it to show the lines of the circulation, and if this



Isobars in warm-center cyclone.

FIG. 11.—Ferrel's circulation in warm-center cyclones.



Isobars in cold-center cyclones.

FIG. 12.—Ferrel's circulation in cold-center cyclones.

be rotated on a turntable a form of motion can be produced quite similar to the one Ferrel proposed to explain the mechanism of storms. This circulation can be generated by any agency which will make a vertical current in the center of the fluid, as a lamp on the lower side, or a paddle screw at the top. A lump of ice on the center of a rotating plane will give a circulation which is like that of the general cyclone over the hemisphere. Now this experiment is open to at least three objections of a very serious nature when it is attempted to apply the lines of the model to the processes in nature. It is not enough to show that there is an inflow at the bottom and an outflow at the top, in logarithmic spiral curves, to conclude that the analogue is satisfactory. Therein lies an assumption which in fact begs the entire question. The great difficulty is that the circulation in the general cyclone consists of the same mass of air, which repeatedly passes through certain paths in consequence of the boundary conditions. The limited mass of fluid in the cylindrical vessel is also the same mass set in circulation, being bounded by the top and bottom surfaces and the curved sides, corresponding with the ground and top of the moving air and the plane of the equator. It has by no means been shown that the air concerned in the local cyclone consists of the same air moving over and over again in similar paths, and it is first necessary to do this in order to establish an analogue of that kind. The evidence from the cloud circulations proves that the cyclone is a form of circulation of the stationary type of configuration, through which fresh portions of the atmosphere continue to stream. If such is the case the analogue described above is inapplicable, and the deductions which have been so commonly drawn from it are quite incorrect. (2) There is no pericyclone discoverable in the records based upon many storms. Ferrel tried to show that the high-area pressures observed on the maps are the resultants of two or more overlapping pericyclones. But the detailed construction shown in Charts 15–35 of the International Cloud Report gives no support to this form of circulation. (3) Evidence of true cyclonic outflow at the top at some distance above the ground is probably entirely lacking. The cyclonic components of

Table 10, paper III, prove that the radial velocity is inward from the ground to the top of the cyclone. It is not our purpose at this point to explain the principles of the circulation that actually exists, but simply to indicate that the Ferrel cyclone, though perfectly possible under certain conditions, is not the type which storms follow in their construction. It is certain that the supposed analogue between the local and the general cyclone is not sustained by the evidence, and if the observed movement of the atmosphere can be accounted for on other principles, in conformity with the observations, it will only add to the force of the position here taken that the Ferrel local cyclone is merely one of many idealized cases. For these reasons we therefore are obliged to conclude that the Ferrel cyclone by no means conforms to the natural circulation, and need not be further considered. Indeed, Ferrel's teaching regarding the origin of cyclones and anticyclones should be eliminated from modern meteorology.

THE GERMAN SOLUTION.

If we make the abbreviation $\lambda = 2n \cos \theta$, retain the friction term, and make $\frac{dv}{dt} = \frac{\partial v}{\partial t}$, thus rejecting the two small terms, equation 397*b* (2) becomes:

422 $$\frac{\partial v}{\partial t} + \frac{uv}{\varpi} + \lambda u + kv = 0.$$

Taking $\frac{\partial v}{\partial t} = \frac{\partial v}{\partial \varpi}\frac{\partial \varpi}{\partial t} = u\frac{\partial v}{\partial \varpi}$, we obtain

437 $$u\frac{\partial v}{\partial \varpi} + \frac{uv}{\varpi} + \lambda u + kv = 0.$$

There are two solutions of this equation, as shown on pages 598 and 599 of the Cloud Report, namely:

First solution (inner).	Second solution (outer).
$u = -\frac{c}{2}\varpi.$	$u = -\frac{c}{\varpi}.$
$v = +\frac{\lambda}{k-c}\cdot\frac{c}{2}\varpi = -\frac{\lambda}{k-c}u.$	$v = +\frac{\lambda}{k}\cdot\frac{c}{\varpi} = -\frac{\lambda}{k}u.$

These can be expressed in two general laws:

(1.) Parabolic law.	(2.) Hyperbolic law.
$\frac{u}{\varpi} = -\frac{c}{2} =$ constant.	$u\varpi = -c =$ constant.
$\frac{v}{\varpi} = +\frac{\lambda}{k-c}\cdot\frac{c}{2} =$ constant.	$v\varpi = +\frac{\lambda}{k}c =$ constant.

These solutions are readily verified by substitution in the second equation of motion, 397*b*, and the two forms give rise, respectively, to parabolic surfaces on the inside of a certain circle, and to hyperbolic surfaces on the outside of it. Their discussion is given on page 509; an electrical analogue is explained on page 521, and they are further illustrated on pages 619 to 622 of the International Cloud Report. A diagram of the motion is shown in fig. 13 of the present paper. The result is that there is an outer region in which there is no vertical component, $w = 0$, and an inner region in which there is a vertical component which increases with the altitude, $w = cz$; see page 621, Cloud Report. These two regions are separated by a circle where the tangential component velocity, v, is a maximum; the velocity of rotation falls away to the center by the parabolic law, and also for an unlimited distance outward by the hyperbolic law. The inner region has the isobars separated from each other by distances conforming to the law, $d_i = R^2 - \varpi_i^2$, where R is the radius of the circle of maximum velocity, and ϖ_i the radii of the successive isobars; on the outside the distances between isobars are determined by $d_e = 2\,R^2 \log \frac{\varpi_e}{R}$; fig. 13 shows these relative distances and velocities.

Recalling the circulation depicted in Paper III, we a duced to make the following remarks:

The theory common to the German school of meteorol is founded upon the assumption of a vertical central cu like the electric current in a wire, which generates the cy circulation in the inner and the outer parts. Now, there series of difficulties and objections to this view, when it tempted to apply it to the observations of the actual mo of the atmosphere, fully as serious as those which have urged against Professor Ferrel's theory. (1) There is n ficient evidence that the vertical current is of definite origin and powerful enough to influence the enormous cy

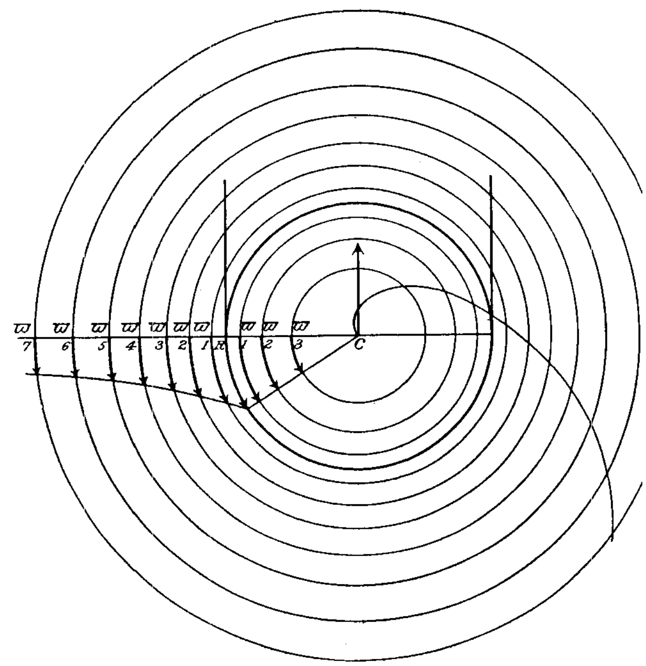


FIG. 13.—Oberbeck's circulation in warm-center cyclones.

disturbances extending horizontally to 1,000 miles in ra These storms are very shallow compared with their widtl 3 or 4 to 1,000 at the greatest depth. An upward centra rent in a small inner region of 200 to 300 miles radius, e locally produced, could hardly cause the disturbances obs on the weather maps. The chief difficulty has been to that there is any sufficient cause for the existence of s current, and the reasons already urged against that view here also, namely, that the disturbing isotherms are no cles, but their gradients lie athwart the cyclone, generally SW to NE; that cyclones exist without precipitation; rainfall does not necessarily produce cyclonic action; and countercurrents from two specific directions, as NW and S into the cyclone, which is not sustained from a supply eq distributed around a center. (2) The adoption of the and outer parts of the cyclone was due to the supposed n sity of avoiding infinitely great velocities at the cen $u = -\frac{c}{\varpi}$ and $v = +\frac{\lambda}{k}\frac{c}{\varpi}$, as would occur for small values It will, of course, be necessary to show how this can be by some other solution. Even if that is accomplished w still other practical difficulties in the German solution ing an inner and an outer part. This requires a maximum tional velocity v at the boundary $\varpi = R$. But our observa give no support to this position any more than to Fe theory that $v=0$ at the boundary of the inner and the parts. A careful examination of our wind velocities show they increase steadily from the outer boundary toward center, when a surface of discontinuity surrounding a center suddenly terminates the radial and tangential velo

The common occurrence of the central calm in hurricanes is sufficient proof of this point. Furthermore, an examination of the cyclonic components (u_2, v_2), Table 10 and fig. 10, shows that the tangential velocity v increases from the outside toward the center without any tendency to fall off. Certainly, in forecasting, no one expects to find the maximum velocities at 200 or 300 miles from the center. The two-part theory itself, although gradually reducing the velocity from a maximum at the boundary R to zero at the center, does not explain the existence of the central calm. (3) While the differential equation has two solutions which give some aspects plausible for this application, yet it is improbable that in such processes of nature as the circulation of the air there should be more than one law actually in operation. That the movement should suddenly jump from one system of forces to another is quite unlikely, unless cause can be shown for it. (4) In spite of skillful devices by which discontinuity in the rotation velocity was overcome, it is evident that there still remains a vertical discontinuity at the boundary, which becomes more and more pronounced with the increase in height above the surface, since $w=cz$. While it is hardly possible to actually observe the vertical components, yet the probabilities are that vertical motion sets in as soon as the isobars which surround the cyclone are closed up, and that all over this area there is a rising current. It may be laid down as a principle that where closed isobars exist there is an ascending or a descending current, according to the direction of the rotation. Where the isobars wander about without closing up, it may be assumed that there is no rising or descending air. In the case of cyclones this is confirmed by the general tendency of precipitation to occur over the entire region of the closed isobars. The preponderance on the eastern side over the western is due to the action of the general drift in the upper strata upon the circulation.

Hence, we conclude that while the Ferrel and the German vortices are each possible and may exist under certain conditions of boundary and distribution of heat, they do not agree with the cyclonic and anticyclonic circulation as given by the cloud observations of 1896–97. Although it is not possible to utilize the Ferrel vortex in further developments because the outer boundary is lacking, and though the German vortex, on the other hand, has apparently a closer application, yet even here it will be found difficult to avail ourselves of it without resorting to a modified method of analysis. We shall show, in part only, how this may be accomplished in the following papers, but the fact remains that the atmospheric circulation is usually too complex to be readily reduced to simple vortex motion of any kind. Hydrodynamic theories of stream lines must, on the other hand, be employed on a larger scale in the meteorology of the future than has been done in the past.

FERREL'S THEORY OF THE GENERAL CIRCULATION OVER A HEMISPHERE.

We can only briefly mention the principles which prevail in Ferrel's and in Oberbeck's solution for the circulation of the atmosphere over a hemisphere of the earth. In this case the boundaries are fixed, namely, the earth's surface, the plane of the equator, the topmost stratum of the atmosphere, and the pole of rotation. The heat distribution is such that the polar regions are cold and the Tropics warm. The primary idea adopted in the mathematical analysis is that of the so-called canal circulation, as, for example, when fluid in a long vessel with rectangular sides is artificially heated at one of its ends, so that the fluid rises at that end, falls at the other, moves in a horizontal direction from the warm end toward the cold end in the upper layers, but from the cold end to the warm end in the lower layers. In the same way the atmosphere is assumed to rise at the Tropics, move northward in the upper strata, fall in the polar zones, and flow southward along the surface of the earth. The effect of the contraction of the meridians, together with the rotation of the earth, is to introduce a complex torque effect, which causes the air to flow rapidly eastward in the temperate zones, especially in the upper strata, and westward in the tropical zones, especially in the lower strata. The general result is shown on fig. 14, for Ferrel's solution; and on fig. 15 the relative component velocities are given for Oberbeck's solution. These two methods of solution have some features in common, and also some of the results agree, and yet there is wide divergence in other respects, as will be indicated. The most conspicuous feature for us to note is that a neutral plane of velocity for the components u along the meridian is obtained, where there is no northward or southward velocity, but above it an increasing northward, and below it an increasing southward velocity proportional to the distance from this plane. We shall have to compare this view with the results of the observations as given in the data of the year 1896–97. The main features of Ferrel's solution of the general cyclone are contained in the following extracts from pages 588–590, International Cloud Report:

Polar equations of motion applicable to the general circulation over a hemisphere.

$$200.\quad -\frac{1}{\rho}\frac{\partial P}{r\partial\theta}=\frac{du}{dt}-\cos\theta\,(2n+\nu)\,v+\frac{uw}{r};\ \text{where}\ \nu=\frac{v}{r\sin\theta}.$$

$$-\frac{1}{\rho}\frac{\partial P}{r\sin\theta\,\partial\lambda}=\frac{dv}{dt}+\cos\theta\,(2n+\nu)\,u+\sin\theta\,(2n+\nu)\,w.$$

$$-\frac{1}{\rho}\frac{\partial P}{\partial r}=\frac{dw}{dt}-\sin\theta\,(2n+\nu)\,v-\frac{u^2}{r}+g.$$

Assumptions are made precisely analogous to those for the local cyclone, except that the temperature is expressed by the equation,

$$t=\Sigma A_s\cos s\theta,\ \text{where,}$$

$$A_0=8.50°.\quad A_1=-1.75°.\quad A_2=-20.95°.\quad A_3=-1.00°.\quad A_4=-2.66°.$$

The equations of general motion take the form,

$$397a.\quad -\frac{\partial\log P_0}{a\partial x}=\frac{du}{dt}-\cos\theta\,(2n+\nu)\,v+k\,u-\frac{gh\,\alpha}{r\,(1+\alpha t)}\,4\,A_2\sin\theta\cos\theta.$$

$$0=\frac{dv}{dt}+\cos\theta\,(2n+\nu)\,u+k\,v.$$

The second equation admits of integration between the pole and the plane of the equator for the entire rotating mass of air, with the resulting equation for the velocity v,

$$v=\left(\frac{2}{3}\cdot\frac{1}{\sin\theta}-\sin\theta\right)r\,n.$$

If $v=0$, $\theta=54°\ 44'$, and the latitude $\varphi=35°\ 16'$ where the velocity reverses direction at the surface.

The locus of $v=0$, above the surface forms an arch over the equator, as shown in fig 14. This is analogous to the curve R of fig. 12 in the cold-center cyclone.

TABLE 13.—*Theoretical west-east velocities.*

Latitude ϕ.	v in miles per hour.
90°	+ ∞ eastward.
80°	+3807 "
70°	+1669 "
60°	+ 865 "
50°	+ 410 "
40°	+ 108 "
35° 16′	0 "
30°	− 100 westward.
20°	− 239 "
10°	− 320 "
Equator 0°	− 346 "

Professor Ferrel was governed in his method of integration by the theorem of the preservation of areas, $\varpi\, v=$constant, depending chiefly upon the velocity v along the parallels of latitude, in order that the sum of the momenta might be equal to zero, $\Sigma mv=0$, for the entire earth, which is a necessary result. However, it led to impossible velocities, v, as shown in Table 13, where excessive westward velocities prevail in the Tropics, and enormous eastward velocities in the polar regions. If we may assume that the location of the neutral plane is determined by the fact that half the air moves northward over it, and half the air southward under it, then the height of this plane should be about 6 kilometers=3.7 miles above the ground, as given in Table 14.

TABLE 14.—*Vertical diminution of pressure.*

Height. *H.*	Pressure. *B.*	Per cent.	Height. *H.*	Pressure. *B.*	Per cent.
km.	*mm.*		*km.*	*mm.*	
0	760	100.0	8	280	36.9
1	671	88.3	9	247	32.6
2	591	77.8	10 (Cirrus)	218	28.7
3	523	68.9	11	193	25.3
4	461	60.7	12	170	22.4
5	407	53.6	13	150	19.8
6 (A. Cu.)	359	47.3	14	133	17.5
7	317	41.8	15	117	15.4

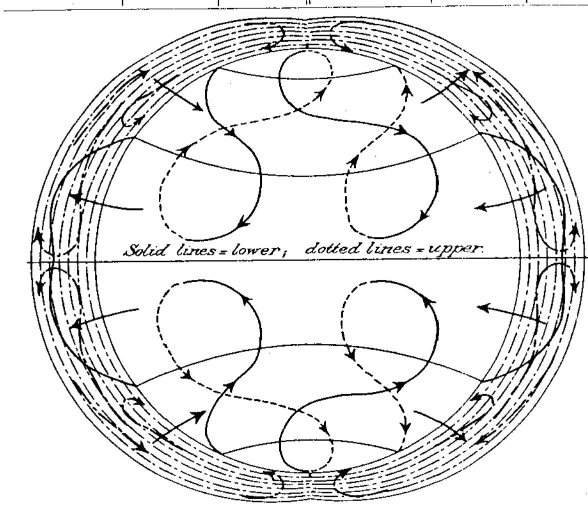


FIG. 14.—Ferrel's general cyclone.

Ferrel attempted to show that the excessive east-west velocities could be reduced to proper proportions by introducing a coefficient of friction, and considering that the sum of the moments Σmvk above the neutral plane must be much greater than the Σmv_0k below that plane. The excess of energy $\Sigma mvk-\Sigma mv_0k=E$, must be used up in overcoming the motion of the atmosphere, employing the term friction to include the forces that retard circulation by internal turbulent motion, or by the action of the adjacent discontinuous surfaces of the larger streams. It is evident, however, even supposing this theory correct, that this source of retardation is by no means sufficient to overcome the great amount of energy which must be consumed in motion to equalize the heat energy derived from the solar radiation in the Tropics. Professor Ferrel never executed a complete integration involving all the component equations of motion, but merely discussed his several equations under different relative conditions, and thus drew out of them certain conceptions of the general circulation of the atmosphere which it was easy to show harmonized fairly well with many of the facts which were known to him at the time of his study, now

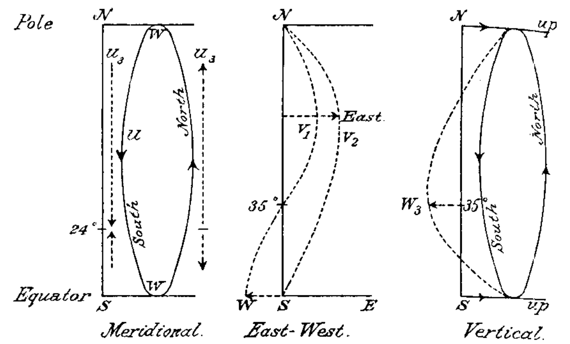


FIG. 15.—Oberbeck's component motions in the general cyclone.

nearly twenty years ago. It has become increasingly difficult, however, to believe that this solution is really as satisfactory as was then supposed.

OBERBECK'S SOLUTION OF THE GENERAL CIRCULATION.

Oberbeck attacked the same problem by a more complete analysis, and reached conclusions which in general accord with those of Ferrel, but differ from his in important particulars. He subdivided the total pressure of the atmosphere into partial pressures, and deduced a series of component velocities which could be computed by means of coefficients distributed at equidistant intervals throughout the atmosphere. An upper boundary was assumed for the atmosphere, but the solution was conducted in such a manner that this limiting stratum, whose height is H, could be changed in relation to the radius of the earth, R. The equations of motion were constructed for an origin at the center of the earth, while Ferrel's origin was on the surface, but the two systems of equations can be shown to be equivalent, so that the mathematical starting point is practically the same in both. Oberbeck held all the components together in one system, and hence, by not discussing them separately, could arrive at some conclusions which are really more instructive than Ferrel's. Yet it will be easily seen that these do not conform sufficiently well to the data of observation to be accepted as the complete solution of the problem.

Taking the component equations and notation given on pages 591–593 of the International Cloud Report, Oberbeck's solution for the component velocities is as follows:

South:

$$u = C\,6 \cos\theta \sin\theta \frac{\sigma}{48}(6h^2 - 15h\sigma + 8\sigma^2).$$

$$u_3 = \frac{2n}{\kappa} R^3 \cos\theta \sin\theta\,(\nu_1 + 2\nu_2 - 7\nu_1\cos^2\theta)\frac{\sigma}{48}(6h^2 - 15h\sigma + 8\sigma^2).$$

East:

$$v_1 = D\sin\theta\,(1 - 3\cos^2\theta)\frac{\sigma}{480}(-9h^5 + 15h^2\sigma^3 - 15h\sigma^4 + 4\sigma^5).$$

$$v_2 = D\;6\;\cos^2\theta\,\frac{\sigma}{960}(20h^2\sigma^2 - 25h\sigma^3 + 8\sigma^4).$$

Zenith:

$$w = C\,(1 - 3\cos^2\theta)\frac{\sigma}{8}(h-\sigma)(3h\sigma - 2\sigma^2).$$

$$w_3 = \frac{2n}{\kappa} R^3\left[\nu_1 + 2\nu_2 - 6\,(4\nu_1 + \nu_2)\cos^2\theta + 35\nu_1\cos^4\theta\right]$$

$$\times\frac{\sigma^2}{48}(h-\sigma)(3h - 2\sigma.)$$

$$h = \frac{H}{R} = \frac{1}{100};\quad \sigma = \left(\frac{0}{10},\ \frac{1}{10},\ \frac{2}{10}\ \cdots\ \frac{10}{10}\right)h;\qquad C = 0.5429\ R^2.$$

$D = 0.00008532\ R^4$.

$r = R + Rh = R + H =$ radius of earth + height of atmosphere.

$r = R + R\sigma = R + \frac{n}{10} Rh =$ radius of earth + height of the stratum σ; h is the maximum value of σ.

Assumed law of relative angular velocity, $\nu = \nu_1 \cos^2 \theta - \nu_2$.

Tables 15, 16, 17, give the relative coefficients of the component velocities in the direction of the meridians, the parallels of latitude, and in the vertical, respectively. By assigning values to H the different velocities may be computed.

I have not been successful in obtaining such velocities as will harmonize at all well with the known movements of the atmosphere, and I have, therefore, been led to distrust the

TABLE 15.

I. *Components on the meridians due to the rotation of the earth.*

$u =$ horizontal currents on meridians. + = south, — = north.

Coefficients of $C \frac{H^3}{R^3} = .5429 \frac{H^3}{R} = \begin{cases} 2.203 \times 10^7 \text{ for } H = 63700^m. \\ 2.203 \times 10^4 \text{ for } H = 6370. \end{cases}$

θ	0°	10°	20°	30°	45°	50°	60°	70°	80°	90°
$\sigma = 1.0$	.0000	—.0213	—.0401	—.0540	—.0614	—.0614	—.0540	—.0401	—.0213	.0000
.9	.0000	— 196	— 368	— 496	— 564	— 564	— 496	— 368	— 196	.0000
.8	.0000	— 151	— 283	— 382	— 434	— 434	— 382	— 283	— 151	.0000
.7	.0000	— 87	— 164	— 221	— 251	— 251	— 221	— 164	— 87	.0000
.6	.0000	— 15	— 29	— 39	— 44	— 44	— 39	— 29	— 15	.0000
.5	.0000	+ 53	+ 100	+ 135	+ 154	+ 154	+ 135	+ 100	+ 53	.0000
.4	.0000	+ 110	+ 206	+ 278	+ 316	+ 316	+ 278	+ 206	+ 110	.0000
.3	.0000	+ 143	+ 268	+ 361	+ 411	+ 411	+ 361	+ 268	+ 143	.0000
.2	.0000	+ 142	+ 266	+ 359	+ 408	+ 408	+ 359	+ 266	+ 142	.0000
.1	.0000	+ 97	+ 183	+ 247	+ 281	+ 281	+ 247	+ 183	+ 97	.0000
.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

II. *Components on the meridians due to the relative motion of the atmosphere.*

$u_3 =$ horizontal currents on meridians. + = south, — = north.

Coefficients of $\frac{2n}{\kappa} R^3 \frac{H^3}{R^3} = .1571 \times 10^{-9} H^3 = \begin{cases} .4062 \times 10^5 \text{ for } H = 63700^m. \\ .4062 \times 10^2 \text{ for } H = 6370. \end{cases}$

θ	0°	10°	20°	30°	45°	50°	60°	70°	80°	90°
$\sigma = 1.0$	.0000	—.0426	—.0713	—.0782	—.0641	—.0376	—.0112	+.0050	+.0073	.0000
.9	.0000	— 392	— 655	— 718	— 588	— 346	— 103	+ 46	+ 67	.0000
.8	.0000	— 301	— 504	— 553	— 452	— 266	— 79	+ 35	+ 51	.0000
.7	.0000	— 174	— 292	— 320	— 262	— 154	— 46	+ 20	+ 30	.0000
.6	.0000	— 31	— 51	— 56	— 46	— 27	— 8	+ 4	+ 5	.0000
.5	.0000	+ 107	+ 178	+ 196	+ 160	+ 94	+ 28	— 12	— 18	.0000
.4	.0000	+ 219	+ 367	+ 402	+ 330	+ 194	+ 58	— 26	— 37	.0000
.3	.0000	+ 285	+ 477	+ 523	+ 428	+ 252	+ 75	— 33	— 49	.0000
.2	.0000	+ 283	+ 473	+ 519	+ 425	+ 250	+ 75	— 33	— 48	.0000
.1	.0000	+ 195	+ 327	+ 357	+ 293	+ 172	+ 51	— 23	— 33	.0000
.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

TABLE 16.

I. *First components on the parallels due to the rotation of the earth.*

$v_1 =$ horizontal currents on parallels. + = east, — = west.

Coefficients of $D \frac{H^6}{R^6} = .8532 \times 10^{-4} \frac{H^6}{R^2} = \begin{cases} 1.405 \times 10^{11} \text{ for } H = 63700^m. \\ 1.405 \times 10^5 \text{ for } H = 6370. \end{cases}$

θ	0°	10°	20°	30°	45°	50°	60°	70°	80°	90°
$\sigma = 1.0$	.00000	+.00346	+.00589	+.00651	+.00509	+.00191	—.00226	—.00636	—.00934	—.01042
.9	.00000	+ 345	+ 588	+ 650	+ 510	+ 190	— 226	— 634	— 932	— 1040
.8	.00000	+ 341	+ 580	+ 641	+ 502	+ 188	— 223	— 626	— 919	— 1026
.7	.00000	+ 328	+ 559	+ 618	+ 484	+ 181	— 215	— 603	— 884	— 989
.6	.00000	+ 307	+ 522	+ 578	+ 452	+ 169	— 201	— 564	— 828	— 924
.5	.00000	+ 275	+ 467	+ 517	+ 404	+ 151	— 179	— 504	— 741	— 827
.4	.00000	+ 231	+ 395	+ 437	+ 342	+ 128	— 152	— 426	— 626	— 699
.3	.00000	+ 181	+ 307	+ 340	+ 266	+ 100	— 118	— 332	— 487	— 544
.2	.00000	+ 123	+ 210	+ 232	+ 181	+ 68	— 81	— 226	— 332	— 371
.1	.00000	+ 62	+ 106	+ 117	+ 91	+ 34	— 41	— 114	— 168	— 187
.0	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000

TABLE 16—Continued.

II. *Second components on the parallels due to the rotation of the earth.*

v_2 = horizontal currents on parallels. + = east, — = west.

Coefficients of $D\frac{H^5}{R^5} = .8532 \times 10^{-4}\frac{H^5}{R} = \begin{cases} 1.405 \times 10^{13} \text{ for } H = 63700^m. \\ 1.405 \times 10^{8} \text{ for } H = 6370. \end{cases}$

θ	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
σ=1.0	.00000	+.00315	+.00565	+.00702	+.00706	+.00592	+.00404	+.00206	+.00056	.00000
.9	.00000	+ 305	+ 547	+ 680	+ 683	+ 573	+ 391	+ 199	+ 54	.00000
.8	.00000	+ 276	+ 495	+ 614	+ 618	+ 518	+ 354	+ 180	+ 49	.00000
.7	.00000	+ 231	+ 415	+ 515	+ 518	+ 435	+ 297	+ 157	+ 41	.00000
.6	.00000	+ 179	+ 321	+ 398	+ 401	+ 336	+ 229	+ 117	+ 32	.00000
.5	.00000	+ 125	+ 225	+ 279	+ 281	+ 235	+ 161	+ 82	+ 22	.00000
.4	.00000	+ 76	+ 136	+ 169	+ 170	+ 142	+ 97	+ 50	+ 13	.00000
.3	.00000	+ 37	+ 67	+ 83	+ 84	+ 70	+ 48	+ 24	+ 7	.00000
.2	.00000	+ 13	+ 24	+ 29	+ 29	+ 25	+ 17	+ 9	+ 2	.00000
.1	.00000	+ 2	+ 4	+ 4	+ 5	+ 4	+ 3	+ 1	0	.00000
.0	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000

TABLE 17.

I. *Vertical components due to the rotation of the earth.*

w = vertical currents. + = ascending, — = descending.

Coefficients of $C\frac{H^4}{R^4} = .5429\frac{H^4}{R^3} = \begin{cases} 2.203 \times 10^{5} \text{ for } H = 63700^m. \\ 2.203 \times 10 \text{ for } H = 6370. \end{cases}$

θ	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
σ=1.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
.9	—.0244	—.0233	—.0202	—.0152	—.0093	—.0029	+.0030	+.0079	+.0111	+.0122
.8	— 448	— 428	— 370	— 280	— 170	— 54	+ 56	+ 145	+ 204	+ 224
.7	— 588	— 562	— 486	— 368	— 224	— 70	+ 74	+ 191	+ 268	+ 294
.6	— 648	— 619	— 535	— 405	— 247	— 78	+ 81	+ 210	+ 295	+ 324
.5	— 624	— 596	— 515	— 390	— 237	— 75	+ 78	+ 202	+ 284	+ 312
.4	— 528	— 504	— 436	— 330	— 201	— 63	+ 66	+ 171	+ 240	+ 264
.3	— 378	— 361	— 312	— 236	— 144	— 45	+ 47	+ 123	+ 172	+ 189
.2	— 208	— 199	— 172	— 130	— 79	— 24	+ 26	+ 68	+ 95	+ 104
.1	— 64	— 61	— 53	— 40	— 24	— 8	+ 8	+ 21	+ 29	+ 32
.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

II. *Vertical components due to the relative motion of the atmosphere.*

w_3 = vertical currents. + = ascending, — = descending.

Coefficients of $\frac{2n}{\kappa}R^3\frac{H^4}{R^4} = .1571 \times 10^{-9}\frac{H^4}{R} = \begin{cases} .4062 \times 10^{3} \text{ for } H = 63700^m. \\ .4062 \times 10^{-1} \text{ for } H = 6370 \end{cases}$

θ	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
σ=1.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
.9	+.0502	+.0444	+.0294	+.0106	—.0050	—.0128	—.0119	—.0053	+.0020	+.0050
.8	+ 927	+ 820	+ 542	+ 197	— 92	— 237	— 220	— 97	+ 37	+ 93
.7	+ 1217	+ 1077	+ 712	+ 258	— 121	— 311	— 289	— 127	+ 49	+ 122
.6	+ 1341	+ 1187	+ 785	+ 285	— 133	— 343	— 319	— 140	+ 53	+ 134
.5	+ 1294	+ 1145	+ 757	+ 275	— 129	— 331	— 307	— 135	+ 52	+ 130
.4	+ 1093	+ 967	+ 639	+ 232	— 109	— 279	— 260	— 114	+ 44	+ 110
.3	+ 782	+ 692	+ 458	+ 166	— 78	— 200	— 186	— 82	+ 31	+ 78
.2	+ 430	+ 380	+ 251	+ 91	— 43	— 110	— 102	— 45	+ 17	+ 43
.1	+ 132	+ 117	+ 77	+ 28	— 13	— 34	— 31	— 14	+ 5	+ 13
.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

validity of this "canal theory" of the circulation, as explained in my report. An inspection of the coefficients, Table 15, shows that in the case of the meridian components, u, the upper northward and the lower southward circulation as deduced for the rotating earth, is somewhat modified by the component u_3 depending on the motion of the atmosphere relative to the ea[rth] itself. The component v along the parallels of latitude, Ta[ble] 16, differs radically from Ferrel's result, and it should be ca[re]fully noted. Oberbeck divides the eastward drift in hig[h] latitudes from the westward drift in lower latitudes at t[he] parallel 35°. The eastward v is a maximum in the neighborhood of latitude 60°, $\theta = 30°$, but vanishes at the poles. This is exactly contrary to Ferrel's result, which made the velocity v a maximum at the pole, before the assumed modification by friction was applied. Oberbeck makes the westward drift a maximum at the plane of the equator, which is certainly not in conformity with the observations. He also makes the westward velocity increase at the equator from the surface to the upper boundary, and show no sign of a reversal from westward to eastward at a moderate elevation, as is generally believed to be the fact, judging from certain well known motions of the air observed in the Tropics.

The United States Weather Bureau has been conducting a series of nephoscope observations in the West Indies for the past three years, and it is hoped that the discussion of these observations, soon to be undertaken, will give us some definite information on this important point.

The second term v_2 modifies v_1, but the two combined, $v = v_1 + v_2$, sustain the conclusions just mentioned. This feature of Oberbeck's solution is so far from conforming to the observed motions of the atmosphere that it seems to me to be inferior in value to Ferrel's for the Tropics. Ferrel's arch over the Tropics, shown in fig. 14, is probably a fact, and if this is so, then the only serious modification required in Ferrel's treatment is to show how the excessive eastward drift in the mid-latitude and polar zones can be effectively checked. It is evident that there must be a large amount of energy available for use in the construction of local cyclones and anticyclones, and that there is, therefore, no pressing need to refer the energy of these motions to any local supply of heat, as is done by those who extend to cyclones the theory of the latent heat of condensation from precipitation originally devised by Espy to explain cumulus clouds and thunderstorms. The components w and w_2, Table 17, show that there is an ascending current in the Tropics, and a descending current in the higher latitudes. Thus, as the result of the theoretical discussion in general, the canal theory has several of its features verified, and yet there are serious discrepancies inherent in both Ferrel's and Oberbeck's solutions.

My statement has suggested by implication that there exists an important principle which has been neglected by these meteorologists. They have each discussed the general and the local cyclones as if they were in a sense *independent of one another*, since separate sources of heat energy are assigned to each, and two characteristic laws of circulation are deduced therefrom. It is much more natural to suppose that these two systems are mutually interdependent, and that the excess of energy of the general cyclone is transformed into the driving forces of the local circulation; also, that the acquired motion of the local cyclone reacts upon and retards the excess of motion of the general cyclone in the temperate zones. The subject becomes, however, excessively complex, and I can only attempt to sketch in general terms in my next paper an outline of this view, hoping some other time to be able to supplement it with a more suitable mathematical analysis, when the study of the observations now in hand has been advanced more nearly to completion.

REVISION OF WOLF'S SUN-SPOT RELATIVE-NUMBERS.

By Prof. A. Wolfer, Zurich, dated March 29, 1902.

The next number (XCIII) of the Astronomische Mittheilungen will contain a new edition of Wolf's table of relative numbers, in which not only will some inaccuracies of the earlier tables—partly errors of computation, partly typographical errors—be expunged, but those older observations that have come to light since the tables were compiled, but have not yet been worked up, will be used in the revision. For the most part these new observations were made at Kremsmünster during the years 1802–1830 and have furnished a very valuable addition to the record of sun spots. I now send you a copy of this corrected and completed series (Table 1), entitled "Observed sun-spot relative-numbers." This table, extending from 1749–1901, replaces that published by Wolf in 1880 in No. L of the Astronomische Mittheilungen, as well as the various copies which afterwards appeared in the Meteorologische Zeitschrift and in the Memorie della Societá degli Spettroscopisti Italiani. [It also replaces the table on pages 505–506, Monthly Weather Review, November 1901.] It contains no error, and is now to be regarded as definitive so long as the complete new reduction of the whole amount of observational material is not executed, for which the preliminary work is now going on; this will, however, apparently require five or six years more.[1]

Those numbers in the above-mentioned table that are entered in heavy-faced type depend wholly on actual observations; those in light-faced type depend in great part upon actual observations, yet also have in part been obtained by means of graphic interpolations between the days of any month that contained observations with considerable gaps between them; the interpolated numbers were combined with the observed numbers in the computation of the monthly means. Only a very few monthly means, in the eighteenth century, depend entirely upon interpolations; by far the larger number are based upon actual observations. But every monthly mean in which even a single interpolated number has been used is shown by light-faced type; in this respect the distinction may have been too rigorous rather than indulgent, and the light-faced type are, therefore, in no sense to be regarded as an indication of the unreliability of the corresponding numbers.

I have thought that it would perhaps be agreeable to you also to possess new editions of the two other tables that are based upon the preceding, namely, the table of "Smoothed relative numbers" and that of the "Epochs of maxima and minima," which are directly deduced from the preceding. In No. XLII of his Astronomische Mittheilungen Wolf has published the smoothed numbers up to 1876, inclusive, and reproductions of these are found in various periodicals and other publications. But there are some errors of computation in this table, and numerous typographical errors occur in the reproductions.

The smoothed relative numbers of Table 2 present the mean course of the spot phenomena; that is to say, without the numerous secondary short-periodical variations that really occur in addition to the 11-year variation. Investigations into the general course of the phenomena and the periods of a higher order should, therefore, be based upon these smoothed numbers and not on those observed. The method of formation of these numbers has been explained by Wolf, in No. XLII of his Astronomische Mittheilungen. The mean of every twelve consecutive observed monthly relative numbers is taken, and every pair of two consecutive means is again united into one mean value according to the following scheme:

1/12 (I + II + III . . . . . . + XII) = n_1, for epoch July 1.
1/12 (II + III + IV. . . . . + XII + I) = n_2, for epoch August 1.
1/2 $(n_1 + n_2) = r$, which is the smoothed number for mid-July.

This method of smoothing is conformable to that which Wolf has used for eliminating the annual period of the variations of magnetic declination when comparing the latter with the solar spots. This consideration was not necessary for the relative numbers but the combination of twelve months into one mean has been adopted in order to secure a uniform method of treating both phenomena. Table 2, which contains these

[1] As Professor Wolfer's revision furnishes us with sun-spot numbers that replace all previous publications the Editor has reproduced them in graphic form on figs. 2 and 3. In these figures the light line represents the observed numbers of Table 1, the heavy line the smoothed numbers of Table 2.—Ed.